STATE LIBRARY OF PENNSYLVANIA
3 0144 00511881 5

REPORT of the INVESTIGATION into the COLLAPSE of TANK 1338

PY
T165.2
R425i

Commonwealth of Pennsylvania
Robert P. Casey, Governor

Tank Collapse Task Force

Pennsylvania State Library
Document Section

The Tank Collapse Task Force consisted of the following members:

Robert Bassett
Office of Attorney General

Linda K. Cochran
Office of Inspector General

Sam Harper
Department of Environmental Resources

Michael J. Heilman
Department of Environmental Resources

Karen Johnson
Department of Environmental Resources

Warren C. Kern
Department of General Services

Gary Niland
Office of Inspector General

Morris E. Ragus
Office of Inspector General

James M. Vighetti
Office of Inspector General

Keith Welks
Department of Environmental Resources

This report would have been impossible without their efforts and without the willingness of their respective organizations to contribute their time to the investigation.

The Task Force also acknowledges and expresses its appreciation for the valuable assistance of Tom Foerster, Robert G. Kroner, Martin Jacobs and other municipal officials of Allegheny County and Jefferson Borough, the Pennsylvania State Police, the Pennsylvania Emergency Management Agency, and the Pennsylvania Departments of Transportation, General Services and Environmental Resources. The Task Force also thanks the staff of the ATLSS Center for its expert assistance and advice.

The Task Force also specifically thanks **John DeLacio** of the Department of Transportation, who was not only a member but also designed and conducted the geotechnical investigation.

PY T165.2 R425i
Pennsylvania. Tank Collapse
Task Force.
Report of the Investigation
into the Collapse of Tank

TANK COLLAPSE TASK FORCE

14th Floor
State Office Building

Pittsburgh, PA 15222
(412) 565-5700

June 22, 1988

Honorable Robert P. Casey, Governor
Commonwealth of Pennsylvania
Main Capitol
Harrisburg, Pennsylvania 17120

Dear Governor Casey:

On January 8, 1988, you directed that an inter-agency team be established to investigate the proximate and contributing causes of the catastrophic failure on January 2 of a large petroleum storage tank located in Floreffe, Pennsylvania. Since that time, the Tank Collapse Task Force has examined the circumstances surrounding the construction of the tank which collapsed, evaluated industry standards and practices, and reviewed applicable governmental involvement and regulation in this field. In conjunction with the National Bureau of Standards, it also reviewed the instantaneous causes of this structural failure.

I am pleased to transmit to you the attached report, which describes the results of these investigative activities and makes certain recommendations. We remain ready to provide such additional assistance as you may deem appropriate.

Respectfully yours,

Keith Welks

KEITH WELKS

EXECUTIVE SUMMARY

The instantaneous causes of the collapse of a recently reconstructed four million gallon Ashland Oil, Inc., diesel fuel tank were a flaw located near the top edge of a steel plate in the first level, ambient temperatures cold enough that the steel in use was prone to react brittlely, and static stress from filling the tank to its permissible capacity with product. The flaw had been introduced into the steel plate decades ago but remained undetected.

The collapse could have been and should have been averted. Both the existence of the flaw and the tendency of the tank steel to react brittlely under normal regional climatic and service conditions were discoverable through the application of good engineering, construction, and inspection practices and by compliance with applicable industry and governmental standards.

The failure by Ashland to find the flaw and establish relevant material properties are the two most serious excursions from sound practice and code compliance by the company, but they are by no means the only ones. Ashland, its employees, and some contractors displayed a pervasive pattern of negligence and ignorance in selecting, assigning, constructing, supervising, and inspecting the reconstruction project.

Reconstruction of the tank in Pennsylvania failed to conform in many significant respects with the applicable industry standard or with the terms of the contract for the project. The construction deficiencies attributable to reassembly, however, did not materially contribute to the collapse of the tank.

The negligent conduct by Ashland which allowed the tank to collapse not only caused extensive environmental damage and widespread community dislocations, but also risked serious or fatal bodily injury. A company employee mounted the roof of the tank less than five minutes before its collapse in order to measure the product level, and routine weekday work assignments brought other employees into the vicinity of the tank.

No statutory or regulatory program presently carried out in Pennsylvania was likely through its efforts to have averted this catastrophe. Although various governmental interests embrace selected aspects of petroleum storage activities, none emphasizes or assigns a priority to the regulation of design and construction practices.

The incidence of sudden and extensive failures of large storage tanks is greater than commonly believed. Consequently, enactment of legislation authorizing the regulation of tank construction and maintenance, providing the power to promulgate appropriate regulatory standards, requiring the demonstration of financial responsibility, and creating the right of the Commonwealth to recover costs from responding to discharges from polluting sources is appropriate and necessary.

Civil enforcement action for environmental damages and costs should be pursued by the Commonwealth against Ashland based not only on the discharge itself but also upon the negligent conduct which led to the discharge. The Commonwealth should also consider civil enforcement action against the tank erector based upon its failure to detect the flaw or ascertain the steel's potential for brittle behavior.

TABLE OF CONTENTS

EXECUTIVE SUMMARY iii

I. INTRODUCTION 1

A. Background of the Incident 1
B. Investigative Scope and Procedures 2

II. TANK RELOCATION PROJECT 4

A. The Ashland Organization 4
B. The Decision to Reconstruct 6
C. The Construction Team 10
D. Dismantling of WI-16 11
E. The Fire Marshall Permit 13
F. The New Tank Foundation 14
G. Construction of Tank 1338 17
H. Leak Testing by STC 18
I. Radiographic Testing 20
J. The Water Test 23
K. Settlement Testing 27
L. Use and Maintenance at Floreffe 27
M. The Tank Collapse 29

III. FAILURE ANALYSIS AND CRITIQUE 37

A. Introduction 37
B. Engineering and Metallurgical Concepts 37
C. Construction Standards 43
D. Causes of the Collapse of Tank 1338 45
E. Geotechnical Investigation 49
F. Other Theories and Failure Scenarios 54
G. Materials Analysis 57
H. Compliance with Applicable Standards and Codes 60
I. Critique of Construction Practices 67

IV. VOLUNTARY AND GOVERNMENTAL REGULATION 97

A. Introduction 97
B. The Fire Marshall Program 97
C. Environmental Programs 100

V. CONCLUSIONS AND RECOMMENDATIONS 102

A. Statutory Recommendations 102
B. Voluntary Standards 107
C. Enforcement Options 108

Digitized by the Internet Archive
in 2016 with funding from
This project is made possible by a grant from the Institute of Museum and Library Services as administered by the Pennsylvania Department of Education through the Office of Commonwealth Libraries

https://archive.org/details/reportofinvestig00penn_1

I. INTRODUCTION

A. Background of the Incident

Just past five o'clock P.M. on January 2, 1988, a large above-ground fuel storage tank located in Floreffe, Allegheny County, Pennsylvania suddenly and without warning collapsed as its shell rent completely from base to roof. The tank collapse unleashed a tsunami of petroleum product as almost 3.9 million gallons of diesel fuel surged out of the failed structure. The crest of this wave washed over nearby earthen dikes, whose intended design for containing a gradual release of petroleum products left them pitifully inadequate to confront the force of this catastrophe.

Perhaps as much as three-quarters of a million gallons of fuel escaped the property of the storage terminal, owned and operated by Ashland Oil, Inc. Much of the uncontained oil poured into the underground wastewater disposal system of the nearby Elrama power generating station of the Duquesne Light Company and through it rushed into the Monongahela River from Duquesne's stormwater discharge pipe.

The force generated on-site by the diesel fuel as the constraints of its tank were tossed aside remains, even upon consideration of the physical evidence, at the outer reaches of the imagination. The steel shell of the failed tank fell twisted and contorted onto the ground, and massive steel columns and other internal support members were bent into acute angles and thrown dozens of feet from their original locations. The shell itself was displaced about 120 feet to the east of its original location. (Photo 1 shows the facility after the collapse but before any debris was removed.) Another tank, almost one hundred feet distant, was crumpled and dented at the point of impact of the surging fuel, as if a low-flying airplane had struck it. (Photo 2.) A second nearby tank bore an uncheckered brownish stain from floor to top, some forty feet off the ground, across one-quarter of its circumference where the escaping fuel splashed against it. Diesel fuel from the spill collected on this tank's roof. A small, uncemented cinder block shed about 120 feet distant had its walls literally swept away, in an image reminiscent of thirty year-old newsreel footage demonstrating the effects of atomic blasts on frame structures, leaving its roof lying neatly on the slab floor. (Photo 3 shows the remains of the shed.)

The enormous volume of diesel fuel discharging into the river very quickly raised the specter of significant deleterious health consequences. As the Monongahela flows north and then west towards Pittsburgh, it provides drinking water for a number of municipal water suppliers of varying size. The fuel in the river moved inexorably toward their intakes. Ultimately, at least five purveyors — and their customers — were forced to deal with service disruptions. The West Allegheny Municipal Authority, serving approximately 10,000 persons, was perhaps the most seriously affected by the spill. It was dependent for its water upon the Robinson Township Authority, which was forced to limit distribution when its intake pipes had to be shut. West Allegheny customers went without normal water service from January 4 until, for some, January 12. The West View Water Company, serving 200,000 people, imposed emergency conservation measures to stretch company storage reserves and maximize other resources. The Midland Borough Water Authority and Western Pennsylvania Water Co. were among the others which suffered effects from degradation of their intake water.

Only heroic measures by local, county, state, and federal officials prevented the catastrophe from causing more pervasive consequences. Hastily arranged interconnections from unaffected water supplies helped blunt the effects during the period that the diesel fuel drifted by intake points. Alterations to treatment systems to screen the contaminants from the incoming water were devised. For areas that could not be safeguarded by these mechanisms, deliveries of drinking water by supply trucks known as water buffaloes were arranged.

At the same time, round-the-clock clean-up efforts were undertaken by Ashland and its con-

tractors, under the supervision of governmental coordinators located at the terminal in Floreffe. Notwithstanding the scope and vigor of these early efforts, the oil slick reached Pittsburgh, where the Monongahela joins with the Allegheny to form the Ohio River. Concentrations of diesel fuel remained high enough in the Ohio to require vigilance and counter-measures in West Virginia and, weeks later, Ohio.

The most reliable data now available suggest that more than 511,000 gallons of diesel fuel from the spill, one of the largest inland incidents ever to have occurred, remain unrecovered and are presumed in the rivers. The known acute effects of the introduction of the diesel fuel into the riverine environment already include the death of at least 11,000 fish and 2,000 birds, and the contamination of dozens of miles of shoreline. The longer term, chronic environmental injuries are expected to be studied in great detail over the next months by federal and state natural resource trustees, by Ashland Oil, Inc., and by various private consultants. These studies of course, will not account for the emotional anguish of more than two million citizens of Pennsylvania and its neighboring states, or for the personal inconveniences and sacrifices they were forced to endure, or for the economic losses suffered by scores of private businesses compelled to limit or curtail entirely their commercial activities during the period of water restriction.

B. Investigative Scope and Procedures

In response to the unparalleled dimensions of the disaster as well as immediate public reports of deviations by Ashland from the accepted standard of care in the recent construction of the tank which collapsed, the Honorable Robert P. Casey, Governor of Pennsylvania, determined that a comprehensive fact-finding investigation of the incident was required. To this end, on January 8, 1988, he directed that an interagency task force be constituted to carry out this investigation. Governor Casey also directed that the investigative activities of this state team be conducted in close coordination with local and Allegheny County officials who had participated effectively in the initial response to the emergency and who commanded relevant local resources and expertise. Finally, it was determined that the state task force inquiry would be conducted in conjunction with a related investigation requested of the National Bureau of Standards ("NBS") by the Honorable Doug Walgren, U.S. Representative for the 18th Congressional District.

The arc of the Task Force investigation, and the report which follows, circumscribed those decision-making activities, material and construction standards, use and maintenance practices, inspection and quality assurance protocols, and all other human parameters relevant to the creation of the specific conditions which proximately and indirectly brought the tank down on January 2. The investigation also examined those instantaneous structural and metallurgical circumstances which actually caused the collapse of the tank. Additionally, the Task Force considered the statutory and regulatory framework — both as written and as practiced — within which the construction and use of this tank was overseen by government regulators. Finally, the Task Force evaluated the responsibility and culpability of those involved in the tank construction project.

The investigative team, however, was not charged with evaluating or quantifying the various consequences of the massive spill. As noted, the calculation of environmental damages will be addressed by the Pennsylvania Department of Environmental Resources, which is well-suited for that task. A review of the efficacy and promptness of the emergency response measures implemented in response to the disaster is being carried out by the Pennsylvania Emergency Management Agency ("PEMA"). Finally, the United States Environmental Protection Agency has formed a group to examine the existing federal regulations which establish standards for spill prevention and control measures applicable to oil storage terminals. The Tank Collapse Task Force opted not to duplicate the efforts of these groups, which possess the requisite expertise in their respective subjects.

The Task Force possessed no intrinsic authority to issue compulsory process to secure witnesses and documents. This potential handicap, however, was mitigated greatly by the coopera-

tion volunteered by most of the corporate and personal principals to this subject. The management and employees of Ashland Oil, Inc., and the management and employees of the Skinner Tank Company, which erected the tank in Pennsylvania, provided documents upon request and willingly agreed to be interviewed, in some instances more than once. They are to be commended for their attitude, all the more so in view of the media scrutiny and private litigation which has ensued in the wake of the collapse. Additionally, the Task Force received generous cooperation from industry trade groups, tank companies, and other large oil companies as it sought to establish accepted standards and practices.

In conducting its investigation, the Task Force worked cooperatively with NBS. In view of that organization's commitment to perform extensive analyses to focus on the instantaneous cause of the collapse, the Task Force elected not to replicate that aspect of the investigation. Accordingly, the scientific conclusions of this report are largely informed by the work of NBS. The Task Force did retain, however, the Center for Advanced Technology for Large Structural Systems ("ATLSS") at Lehigh University to review the NBS work and otherwise advise it on technical matters. ATLSS is one of a handful of National Science Foundation (NSF) Technology Centers. Each NSF center is dedicated to a different technology or area of application. ATLSS' expertise is in the design, construction and analysis of large structures. Ashland, additionally, retained the Battelle Memorial Institute to conduct its own investigation into the cause of the tank collapse. The scope of the Battelle investigation has appeared to approximate that of NBS; it focuses upon the instantaneous causes of the collapse. By agreement of the Task Force, NBS, and Battelle, raw empirical data from laboratory and analytical testing have been freely exchanged in the interests of sound scientific research. Evaluative material, opinions, conclusions and other proprietary materials (including investigative interview reports) have not, however, been formally distributed.

The Task Force, with the invaluable assistance of PEMA and the Pennsylvania State Police, maintained and preserved the collapse scene in an undisturbed state — save for essential alterations necessary for clean-up activities — until a complete investigation of the site had been conducted and specimens for analysis had been identified and removed. At that point, the tank debris was marked and coded and positionally located with the assistance of staff from the Pennsylvania Department of Transportation. It was then removed to a nearby property for longer term storage. (Photo 4 shows the storage site.)

II. TANK RELOCATION PROJECT

A. The Ashland Organization

The ill-fated decision to dismantle Tank Number 16 at the Whiskey Island, Ohio terminal ("WI-16") and reconstruct it in Floreffe as a replacement for the then-existing Tank Number 1338 ("old 1338") arose directly from the intersection of two apparently unrelated and quotidian business considerations faced by Ashland Oil, Inc., in 1985 and 1986. These two matters, which at the time must have appeared fortuitously coincidental, were the sale by Ashland of the Whiskey Island Terminal of its Allied Oil, Inc. subsidiary and the contemporaneous need for extensive repairs or replacement of a large No. 2 fuel oil tank — old 1338 — at the Floreffe Terminal of its Ashland Petroleum Company.

The ultimate owner and operator of the Floreffe Terminal is, of course, Ashland Oil, Inc. Ashland Oil prides itself on its position as America's largest independent refiner, a distinction whose significance may elude those who do not count themselves as votaries of the oil industry. Appreciation of Ashland's position requires some grasp of oil industry segments. There are, in fact, three distinct components predicate to the ultimate sale of petroleum products: exploration and production, refining, and distribution and marketing. Major oil companies, such as Exxon and Shell, are generally integrated across all three sectors. Effectively, this means that they conduct a large portion of exploration and production of crude from wells themselves, refine it into various intermediate and finished salable petroleum products, and ultimately vend it to final customers through branded service stations or fuel distributorships.

Other members of the industry community, such as Ashland Oil, attempt to find their market niche by focusing on less than all three industry blocks. In recent years, Ashland Oil has refined and produced only about ten percent of its own crude oil. It has directed its energies and attention to the subsequent links in the industry chain—refining and marketing.

It is from this emphasis that Ashland Oil derives its "prominence" as the largest independent refiner in the oil industry. The umbrella of Ashland Oil, Inc., itself encompasses seven subsidiaries. These include companies involved in limited crude oil and gas exploration and production, highway construction, coal mining, and chemical and petrochemical manufacturing. In addition, Ashland Oil, Inc., includes its SuperAmerica group, which operates more than 450 service station/convenience stores in sixteen states, and Valvoline, the nation's number three marketer of branded, packaged motor oil. Finally, the jewel of the Ashland Oil crown is the Ashland Petroleum Company. Ashland Petroleum Company ("APC" or "Ashland") boasted a refining capacity of 346,500 barrels of crude oil per day in 1987. This figure, which represents almost three percent of American refining capability, places Ashland Oil approximately twelfth among oil companies in terms of refining and sales. APC sells a full range of petroleum products to resellers and consumer accounts in 35 states. In Pennsylvania alone, APC operates four terminals with 125 tanks of 5000 barrels (210,000 gallons) or greater capacity, and dozens of smaller tanks. Driven substantially by this refining capacity, Ashland Oil reported a net income in 1987 of $133 million dollars on sales and revenues of $7.2 billion dollars. Reflecting the recent downward trend in the oil industry, both these figures represented declines from fiscal 1986 and 1985 earnings.

A number of individuals employed by the Ashland Petroleum Company played important and continuing roles in the planning and decision-making for the relocation of WI-16 to the Floreffe Terminal. Five of these were employed by the Supply and Transportation Group of APC, and the other two by the Manufacturing and Technical Group. In order to reduce interruptions and digressions in the chronological narrative to a minimum, capsule descriptions of the background and general responsibilities of these key

participants are presented here, at the outset. (Figure 1 is a simplified organizational chart of APC during the relevant time.)

George Morgan was the Floreffe terminal manager at the time of the collapse. Morgan, 55 years old, started employment with APC in 1958 after stints with Texaco and Humble Oil. Morgan began work for APC as a loader, and later performed such duties as dispatching, trucking, and warehousing. He was eventually promoted to assistant terminal manager and, several years ago, named terminal manager at Floreffe. As such, his duties included day-to-day operational control of the facility, supervising employees, scheduling terminal operators, coordinating product shipment deliveries, maintaining inventory records, and insuring that tanks and equipment were in sound working order. Morgan does not, according to his personal understanding of his responsibilities, arrange for necessary repairs himself. Morgan is still the terminal manager. His immediate supervisor is Wesley McIntosh.

Wesley "Paul" McIntosh was 52 years old and a district terminal manager for APC at the time of the collapse, a position he continues to hold. McIntosh started with APC in 1958 and has worked continuously for it since that time. From June of 1973 until January of 1985, he was the terminal manager for the Floreffe Terminal. He was then promoted to district terminal manager, responsible for supervising some ten APC storage and marketing terminals in three states. Floreffe Terminal is within his district. McIntosh is responsible for over-seeing the day-to-day operations of the various terminals assigned to him, working directly with the terminal managers and acting as the communications link between the terminals and APC headquarters in Ashland, Kentucky. McIntosh's personal office is located at the Floreffe Terminal. According to him, however, he travels extensively to his various terminals and consequently spends little actual time at Floreffe. At the time of the WI-16/1338 project and until sometime shortly after the collapse, McIntosh reported to John Welsh.

John R. Welsh, II, is an operations manager for the Trucks and Terminals section of APC. Welsh, 40, has an M.B.A. in marketing from the University of Cincinnati and started with APC in 1973. He began as an administrative assistant, became a senior buyer, and then became an administrative assistant to the Ashland vice-president for Traffic and Logistics. In 1982 he was promoted to his present position. As operations manager, he supervises several district managers and is responsible for personnel and operational activities in these districts. The organizational function of Trucks and Terminals is to assure the delivery of APC products to its storage terminals and distribution to its customers. Through December 31, 1987, Welsh managed Districts 1 and 2, which were known as the Mid-West Area and encompassed terminals in some nine states. On January 1, 1988, Welsh's responsibilities changed when Paul Van Norman became operations manager for District 2, which includes the Floreffe Terminal. This change, unrelated to the WI-16/1338 project, occurred just one day before the collapse. Welsh is based in Ashland, Kentucky. At all times relevant to this report, Welsh reported to Robert West.

James E. Ross, 44 years old, held an organizational position with APC lateral and essentially equivalent to those of Welsh and Van Norman. Ross began with APC in 1966 or 1967 as a construction foreman and worked his way up as manager of the engineering division, to manager of product development for Allied Oil in 1980, to senior facilities engineer in 1984, and to assistant facilities manager in 1985. In 1986, he was made manager of Facilities for the Trucks and Terminals Department. As such, Ross was responsible for exercising overall management of fixed facilities with respect to design, maintenance, capital improvements, management training, and utilities management. In short, according to Ross, if the sales or terminal managers needed major repairs or a tank erected at a terminal, they would notify him (or his section). He would develop a conceptual proposal with appropriate parameters and send it to the engineering department. Engineering would specifically design the project and prepare cost estimates for various options, all of which would then be returned to the facilities management department. Ross and his staff would examine this product and, in concert with the engineering group, recommend the best option to corporate management. Along with Welsh and Van Norman, Ross reported to Robert West. Ross was also located in Ashland.

Robert Nelson West was, until shortly after the tank collapse, the Director of Surface Transportation and Facilities. Now 48 years of age,

West started with APC in 1964 and held such positions as terminal operator, administrative assistant, operations manager of terminals and trucks, and group executive assistant before being made Director in 1985. His responsibilities included supervising the area and facilities managers, overseeing the Trucks and Terminals group, and controlling 23 truck terminals. West had power of attorney for APC and could sign contracts with vendors on behalf of the company. He was reassigned to become group executive assistant after the January 2, 1988, collapse.

The remaining two key APC participants are employees in the engineering section of the Manufacturing and Technical Group, rather than the Supply and Transportation Group. Robert Walters, who served as the project engineer for the tank relocation effort, started as a draftsman with APC in 1973, while still in vocational-technical school, through the company's cooperative education program. In July of that year, after receiving a drafting diploma from Ashland State Vo-Tech, Walters became a full-time employee and subsequently progressed from level B draftsman to level A draftsman to lead draftsman. In 1976 he was promoted to the position of project engineer in Facilities Engineering, a subdivision of the APC Engineering Department. Walters, who was 34 years old at the time of the collapse, is neither a college graduate nor a licensed professional engineer. After joining APC, Walters received diplomas from the International Correspondence School in mechanical engineering and as a master electrician. As a project engineer, Walters was responsible for estimating, planning, designing, requisitioning, and scheduling major capital construction projects and, during the actual construction phases, for cost control, field supervision, and assistance to construction personnel. Walters' supervisor during the WI-16/1338 project was Paul Stringer.

Paul E. Stringer, Sr., had been the manager of the Facilities Engineering Department within APC since May of 1985. Stringer started with APC in 1964 also as a draftsman, after completing two years of college and two years of vocational-technical education. He subsequently worked as a construction supervisor, engineer and chief engineer before his promotion to facilities engineering manager. Stringer's job required him to manage the execution of major maintenance and expansion projects for APC. He supervised a staff of 22 employees, of whom approximately half were full-time permanent APC workers. Two of the full-time employees were professional engineers; Stringer himself is not. Stringer was 48 at the time of the tank collapse.

Although other APC employees played roles of varying significance during the project, they were generally not as critical as these seven. Their participation spans the tank relocation effort, from inception to collapse.

B. The Decision to Reconstruct

The fountainhead of the WI-16/1338 project can be located in discussions between APC and an industrial neighbor of one of its marketing locations. In the spring of 1985, the International Salt Company undertook negotiations with Ashland regarding the possible purchase of the Whiskey Island Terminal Facility of Allied Oil, Inc., an Ashland subsidiary. The terminal, near Cleveland, Ohio, was located next to a plant of International Salt used in the processing and manufacturing of various salt products, including salt for consumer and industrial purposes. International Salt wished to expand and improve its docking operations by acquiring the land on which the heavy oil terminal was situated.

The Whiskey Island Terminal in 1985 comprised some 19 storage tanks of various sizes. At least ten of these tanks were sufficiently small to be lumped, on some Ashland documents, into a category identified as "small tanks/size varies." Of the remaining tanks, WI-16 was the largest, with a 48 foot diameter, 120 foot height, and 96 thousand barrel capacity. A welded, insulated tank then used for storing No. 6 oil, WI-16 suffered from a somewhat uncertain pedigree. A handwritten note by Paul Stringer from March 10, 1986, regarding an inspection of the tank bears the entry "1940, C.B.I." C.B.I. is a commonly used abbreviation for the Chicago Bridge and Iron Company, a leading tank and pressure vessel manufacturer. C.B.I. representative Don Simpson apparently confirmed to Ashland officials that the tank was built by his firm in 1940. In

statements to Task Force investigators, C.B.I. acknowledged that it possessed a "contract card" for the tank which stated that it had been built in 1940. However, C.B.I. also stated that the existence of the card meant that all other documents pertaining to this structure had been previously discarded. Finally, C.B.I. maintained that, in the absence of such additional records, there was no conclusive way to link the "contract card" with WI-16 to prove its origin, and that the date itself might be incorrect by a year or so.

Adding to the uncertainty, in response to a request during the investigation for documentation regarding the original construction of WI-16, Ashland could only identify and produce a copy of a tank construction plate which reads "BUILT BY McCLINTIC-MARSHALL CORPORATION" and contains a 1934 date. The dimensions shown on this construction plate are somewhat smaller than those associated with WI-16, casting some doubt about whether it actually came from WI-16. Ashland representatives speculated that the nameplate referred to an entirely different tank from which a manway was at one time removed and shifted to WI-16, thereby introducing a component originally built by McClintic-Marshall. APC could not document this theory. This mystery, unfortunately, could not be pursued with McClintic-Marshall itself. The company was acquired by Bethlehem Steel in the 1930's and eventually folded into its fabricated steel division. That division was, in turn, itself later discontinued and no records from the era in question remain.

Finally, in a written response to the Honorable D. Michael Fisher of the Pennsylvania Senate, Ashland vice-president Philip W. Block stated simply that "Most of the steel in [reconstructed] Tank 1338 is over 45 years old." This response, due to its exiguous detail, is equally applicable to a tank constructed in 1940 or 1934.

Ashland Petroleum Company management concluded, either independently or as a function of the sale negotiations, that there was in fact no long-term need for the Whiskey Island facility. Accordingly, the negotiations with International Salt for the transfer of the property proceeded. At some point in this process, the prospective purchaser determined that it had no use for some or all of the terminal storage tanks and their removal became an element of the negotiations. Ultimately, as a term of the December 16, 1985 agreement of sale, Ashland committed to emptying and cleaning, by the time of the closing of the transaction, WI-16 and other structures at the terminal. Additionally, the sales agreement gave Ashland the right to remove any improvements from the premises until June 3, 1986, the date of closing.

At virtually the same time, the Trucks and Terminals department of the Ashland Petroleum Company was, quite independently, in the process of examining the economics of refurbishing or replacing a large, above-ground diesel fuel tank at its Floreffe, Pennsylvania terminal. Floreffe is in southeastern Allegheny County, one mile south of Lock and Dam No. 3 on the Monongahela River. It is approximately fifteen miles in a direct line to the Point in Pittsburgh. (Figure 2.) Ashland Oil and Refining Co. (a predecessor entity) acquired the majority of the property in 1941 from the American Bridge Company. The terminal presently consists of approximately 17 acres in a trapezoidal shape located between State Route 837 and the Monongahela River plus a one and one-half acre parcel across Route 837 which is roughly in the shape of a baseball field home plate. At its closest point, the terminal boundary is approximately 600 feet from the river. The terminal has almost 50 tanks for the storage and distribution of light petroleum and gasoline products and asphalt ranging in size from just over 30,000 gallons to just under four million gallons. It is criss-crossed with above and below-ground pipes. (Photo 5 shows the terminal.)

The tank to be replaced — old 1338 — was a 70,000 barrel, riveted type cone roof tank located on the side of the Ashland property immediately adjacent to State Route 837. Ironically, this tank itself did not pass its entire useful life at the Floreffe facility. According to Ashland records, old 1338 was first constructed in the early 1900's elsewhere, and dismantled, moved, and then re-erected at Floreffe in 1943.

In an April 29, 1985, company memorandum, Wesley McIntosh informed John Welsh that old 1338 needed to be painted; according to a later memorandum, the tank also required a new roof and supporting structure, a new floor, and the application of an epoxy sealant to all riveted shell seams. Comparable repairs had been made previ-

ously on old 1338. On the April 29 McIntosh memorandum, a handwritten entry above the typed reference to 1338 reads "1986, new tank." It is not clear who entered this notation, or when it was added, and as late as March 21, 1986, McIntosh sent a memo to John Welsh describing fiscal 1987 budget items which ambiguously referred to the upcoming repair or replacement of 1338 and painting of it.

The process by which Ashland officials examined the prospects for rehabilitation or replacing the storage capacity of old 1338 appears, at least in retrospect, to have been quite casual and superficial. The ultimate decision-making authority was apparently diffused across a number of individuals. Robert West, the Manager of Trucks and Terminals, recalls that in 1985 he was advised that old 1338 needed repairs performed on it. An *ad hoc* group, consisting of at least West, John Welsh, James Ross, and several engineers, was formed to examine the options available to address the deterioration of old 1338. John Welsh agrees that he was a member of this group, but claims that its membership included Wesley McIntosh and Robert Walters from the Facilities Engineering Department. McIntosh, however, maintains that he was not a participant in discussions about replacement of old 1338, does not know who made the decision to relocate WI-16 to Floreffe, and, notwithstanding his position as the district manager for that location, did not learn of this decision until the spring of 1986. The precise role McIntosh played is not particularly clarified by his aforementioned March 21, 1986, memo, in which he acknowledges the possible replacement of old 1338.

Walters, similarly, denies any notion that he was a decision-maker in this process, and asserts that the decision must have been made by Welsh, Ross, or West. Walters, however, does agree, as will develop shortly, that he enjoyed input into the review. Finally, APC, in its current official version of events as presented in the Block letter of March 16, 1988, identifies the project team as consisting of Ross, Walters, and Paul Stringer of the engineering department. The Block letter also identifies, in the same section describing the project team, Floreffe Terminal Manager George Morgan, implying that he played some decision-making role. Morgan disagrees, claiming that he did not even learn about the plan to bring WI-16 to Floreffe until the summer of 1986, long after the key decisions had been reached. Stringer, similarly, describes his role in the project as limited to assigning staff and requesting inspection work from another APC section.

In any event, this group of somewhat imprecise membership examined the question of repairing old 1338 through the fall of 1985. According to Welsh, their consideration was informed by the knowledge that the Whiskey Island facility was being sold and that its tanks would become available in 1986. Sometime in the fall of 1985, Ross and/or Paul Stringer, the manager of the Facilities Engineering Department, directed Walters to analyze the comparative economics of repairing old 1338 or moving an existing tank from a different location (e.g., Whiskey Island) to Floreffe. Walters prepared such an analysis and submitted the figures to Ross. Walters has stated that he did not examine the cost or feasibility of erecting a new tank at Floreffe.

During the time that Walters was compiling this data, Paul Stringer, the manager of the Facilities Engineering Department, was asked to conduct an inspection of WI-16. Although Stringer is not certain, he believes the request was made by Welsh. Stringer in turn asked Elwood McCoy, the manager of the Inspection Department, to perform this examination; his handwritten request asks for a "Metal Inspection". McCoy assigned it to one of his inspectors, Mike Nichols. Nichols visited the tank on March 12, 1986 and conducted a visual and ultra-sonic inspection. Nichols expressly understood at the time of his inspection that WI-16 was being considered for dismantling and shipment to another site. The scope of his inspection was limited to the structural condition of the tank. He did not pursue questions of metallurgy, such as strength and toughness, nor did he seek historic documentation about the steel in WI-16 or its service history at Whiskey Island.

In a March 17, 1986 inspection report, Nichols wrote that "all areas of the tank that could be inspected was (sic) found in good condition except the floor....the floor should not be reused." Nichols also noted that his examination revealed "no severe metal loss or corrosion...." Nichols explained that he had removed insulation in numerous areas to reach these conclusions, but that his

inspection was "limited slightly due to the tank being insulated and no scaffolds or ladders inside."

In his recommendations, Nichols made several suggestions, including one directed at the method of tank dismantling. On his handwritten inspection sheet, Nichols entered "cut tank down in weld seams," but the typed report changes this to read "Disassemble tank by cutting at the weld seams." A second, typed, recommendation called for a minimum four inch area all the way around each plate to be sandblasted clean. Nichols explained that it was his intention that this would mean that old 1338 should be cut down through the middle of the old welds, and that the old welds should be completely removed. This procedure was based on his own knowledge of welding. The inspection report with these recommendations was approved in writing by McCoy. Walters, when asked during the investigation about these recommendations, stated that he did not believe it made any difference whether all the old weld material was removed by cutting a tank down through such welds or if dismantling was carried out by simply cutting to the side of old welds. Walters admitted, however, that he was not very knowledgeable about welding. He did not know how WI-16 was in fact cut down. Shortly after Nichols' inspection report was prepared, it was reviewed and approved by Paul Stringer. According to Stringer, the report was then forwarded to Welsh and Ross for their use in considering whether to dismantle WI-16 and move it to Floreffe.

An April 9, 1986 memorandum from Ross to West was identified by Walters as incorporating the information he had compiled. In the memorandum, Ross identifies three options: repairing old 1338, relocating WI-16 to Floreffe, or relocating a smaller, 55,000 barrel tank from an Ashland terminal in Birmingport, Alabama, to Floreffe. The cost to repair old 1338, assuming that a new floor would be necessary, was projected as $275,000 or $3.93 per barrel. Relocation of WI-16 would require $330,000 but, because of the larger volume, this would represent a per unit cost of only $3.44 per barrel. The smallest tank, from Birmingport, would cost $250,000, or $4.55 per barrel. The memo notes that "the Whiskey Island tank is about 50 years old" but that the refinery engineering inspection team had determined it to be in good condition. Ross concluded his comparison of these options by suggesting that he and West discuss the matter at West's convenience.

The precise manner by which the decision to tear down WI-16 and re-assemble it at Floreffe was finally made is extremely difficult to fix. Welsh forthrightly stated that the decision was made by the Welsh-McIntosh-West-Walters-Ross group following a review of the comparative cost estimates. West essentially agrees with this account. McIntosh, however, claimed to have no knowledge about how the decision was made, and Walters claimed that he could only surmise that the decision had to have been made by Welsh, Ross, or West. Stringer believed that no one person would have made the final decision. He assumed that a number of high APC officials, including his boss, H.A. "Tony" Raiche, Lloyd Bush, the Vice-President for Engineering, Robert Keifer, Vice-President for Marine and Surface Transportation, Welsh, and West must all have agreed to the project. No other participant or witness agrees with Stringer that Bush and Keifer played any roles in the process. APC, in the Block letter, simply says that the "precise allocation of responsibilities among these individuals [of the project team which APC identified] and other Ashland employees is still under investigation."

Nonetheless, it appears that the actual decision was made between April 9, 1986, the date of the memo to West from Ross transmitting the cost information, and April 30. On the latter date, George Morgan, the Floreffe terminal manager, wrote a memo stating that old 1338 was to "be taken out of service to be dismantled." The date of this communication appears to conflict with Morgan's position that he first learned of the plan in the summer of 1986. On the same date, Walters submitted an Authorization For Expenditure, or AFE, in the amount of $190,200 to West for the purpose of moving WI-16 to Floreffe to replace old 1338 in No. 2 fuel oil service. The AFE was the internal Ashland mechanism by which funds necessary for such projects could be encumbered and the contracting process commenced. West approved it, as did other necessary APC administrative personnel. With this step, Ashland committed itself to the chain of events leading to the January 2, 1988 structural collapse.

C. The Construction Team

A number of things occurred at approximately the same time as Walters' preparation and submission of the AFE to West. According to Stringer, he would have received a copy of the approved AFE sometime after its preparation and, upon receipt of it, he assigned Walters to be project engineer for the relocation of WI-16 as replacement for old 1338. This assignment was apparently based upon Walters' prior involvement in preparing economic comparisons for the project and his resultant familiarity with the task. In reality, it seems apparent that Walters must have been at least informally designated or expected to be the project engineer sometime earlier than his April 30 AFE. This conclusion follows rather plainly from the celerity with which the internal AFE was converted by Walters into a binding document with an outside contractor: the contract with Skinner Tank Company ("STC") is dated the very next day, May 1, 1986. Walters' involvement in the estimating of costs also supports the conclusion that he had tacitly been identified as a lead employee at an early stage.

As project engineer, Walters was responsible for overseeing the tank relocation from start to finish. This included the calculation of projected costs, preparing descriptions of the scope of work, writing specifications, preparing drawings, soliciting and evaluating bids, selecting the contractor, and supervising the performance of the work. Walters had been project engineer on one prior tank job, in which Ashland had assisted in the construction of two 5,000 barrel jet fuel tanks for one of its important customers, Airborne Express. This project, carried out in 1983 in Wilmington, Ohio, was also performed by STC. Walters first became familiar with STC and its work at that time. This apparently remained his only contact with STC until the instant project.

In soliciting bids for the job, Walters relied upon a qualified bidders list that Ashland maintained. The firms on this list were those that had previously provided Ashland with proof of their insurance coverage. While many other large oil companies maintain similar qualified bidders lists, the criteria for eligibility seem substantially stricter than those applied by Ashland, involving proof of competence or qualifications. Exxon, for example, sends inspectors to prospective fabrication and/or erection firms to examine their documentary qualifications and actual shop procedures before allowing companies onto its qualified bidders list. The apparent sole prerequisite for entry onto the Ashland list, however, is insurability. In fact, STC had performed no work directly nor demonstrated its skills and capabilities for Ashland prior to the relocation of WI-16.

Walters apparently solicited the bids for the project by telephone. Representatives of both Baker Tank Co. and Nacogdoches Fabrication, ultimately unsuccessful bidders on the job, recall receiving oral bid solicitations for this project in 1986. Ashland has to date been unable to locate or produce any contemporaneous written requests for bids it issued for the actual tank relocation, although written bid specifications for auxiliary work have been identified. STC produced during the investigation a copy of its April 29, 1986 "Proposal" for the WI-16 relocation which was addressed to Walters. This proposal offers to complete the WI-16 work and for an additional $20,000 to dismantle the existing Floreffe tank.

On May 1, 1986, Ashland Petroleum Company mailed to STC a form contract, bearing that date, for the job. The contract price was $174,391.00; this was in fact the lowest bid received by Walters. The Baker bid, dated May 5, 1986, on that company's formal "Quotation" sheet, was for $214,023.00. No records remain which establish that Nacogdoches submitted a written bid, but Stringer has stated that Skinner's bid was the least costly. The scope of work in the contract sent to STC reads in its entirety as follows:

> To cut down one 96,000 barrel (120'x 48') tank at the Cleveland Whiskey Island Terminal, remove foam insulation from all sheets and bag up for disposal, transport tank material to the Floreffe, Pennsylvania Terminal, and re-erect tank. Contractor to supply new 1/4" steel floor. Re-erection to be in accordance with API 650 latest edition.

Other contract terms required STC to commence work by May 12, 1986, and substantially complete it by July 31, 1986, and obligated STC to

obtain all necessary permits and licenses for the accomplishment of the work.

The firm chosen by Ashland and Walters is based in Yale, Oklahoma, approximately midway between Tulsa and Stillwater. Skinner Tank Company is the corporate successor, formed in 1983, to a family tank construction business called Skinner Tank Construction. The latter company was run by partners Larry G. Skinner and his father Lester 0. Skinner, and claimed to have been involved in tank design, fabrication and construction for forty years. Lester became president and Larry vice-president and chief operating officer of Skinner Tank Company. STC is, obviously, also in the business of dismantling and rebuilding various storage tanks sized from 1,000 to 150,000 barrels. Its motto, ironically enough, is "We Erect Monuments to Progress."

STC claims to employ approximately 70 full-time workers, with more than three-quarters being welders. STC has only two full-time draftsmen and no design engineers. Neither of the Skinners is himself an engineer, but the firm will retain consulting engineers if a contract specifically requires it. STC averages about 100 to 150 tank construction projects a year and Larry Skinner estimated that his company had dismantled over 1000 tanks. Skinner takes obvious pride in the degree of experience and on-the-job training he has absorbed over the years.

STC does not require any formalized training of its welders, but it does require that they pass a welding examination which, since approximately 1986, has been administered by in-house personnel. STC does not have any written procedures or policy regarding types of welds each welder must be able to make, nor does it have written policies for the kinds of welding rods or amperage to be used, or written restrictions on welding based upon weather conditions. Although Larry Skinner claimed that STC maintains welding procedures and specifications which demonstrate the quality and strength of company construction techniques, STC was either unable or unwilling to produce these documents during the investigation.

Skinner quite obviously relies heavily upon the experience, competence, and presumed common sense of his employees. Both Skinner and Walters agree that no blueprints, schematics or diagrams for the dismantling of WI-16 were prepared or examined. To Skinner, such an omission, if he would even identify it as such, was irrelevant. He flatly stated that there was only one way to reconstruct a tank, and that was in the same way that it had been dismantled.

D. Dismantling of WI-16

On May 13, 1986, a crew of six STC employees arrived on site at Whiskey Island to begin dismantling WI-16. The work crew was under the supervision of Randy Fritchman. Fritchman started his employ with the Skinner Construction Co. in 1976 as helper, and progressively worked his way up to welder and then to foreman. He had been involved in several tank dismantlings and perhaps fifteen or twenty assemblies. He had received instruction from Larry Skinner in the accepted STC method for these activities.

According to Fritchman, the removal of WI-16 was essentially uneventful. His crew remained on site for approximately five weeks, with about half that time being spent literally on cutting the tank down. The first step was to remove a small strip of the existing insulation from the area around the outside vertical weld seams of the tank, utilizing a special scraping tool fabricated by STC for the activity. Then, scaffolding was erected and insulation was scraped from the horizontal welds. Once these paths or tracks to the tank metal were completed, the tank was cut into approximately eight foot by thirty-two foot plates. This cutting was done from bottom to top of the tank, with six inch strips left intact between sheets to maintain the tank structure during the cutting.

After this preliminary cutting was finished, the roof was removed with a crane. Then a door was cut into the shell and the crane moved inside to remove internal support members. Finally, the tank was dismantled, from the roof to the ground, using a crane and special quick-release clamps common in the tank construction industry.

During the dismantling process, the individual steel sheets were numbered to aid in proper

reassembly. Various sides of each sheet were identified with letters and/or numbers placed on them during cutting. The numbers follow what STC calls a "match-mark" system, so that the same sheets will be attached to each other during reconstruction. (This is illustrated in Photo 6, a photograph of a different STC tank project).

The precise cutting method followed by Fritchman was also taught to him by Larry Skinner. The vertical cuts were made just to the right of the "puddle" of the existing weld, thus leaving all the existing weld material on only one of the two sheets created. Similarly, horizontal cuts were made directly above, as closely as possible, to the existing weld material. (Figure 3, a drawing, depicts this.) Workers cut manually, not with a guide, using acetylene torches. Neither Fritchman nor Skinner was apparently shown or told about Nichols' inspection recommendations, either with regard to cutting through the prior welds or about sandblasting four inches on either side of the cut.

Fritchman stated that he did not know why cutting through the old welds would be inappropriate, but it was not the STC method. Larry Skinner, however, claimed that tank shell sheets cut down through the old welds would require grinding to remove weld material on both sides of the cut, as well as some base metal on each side, before reassembly. In Skinner's opinion, this would somehow change the structural integrity of the tank. No other tank construction or oil production and storage companies, when asked about this theory, were able to offer support for the notion that preparing the sheets in this fashion for new welding would itself weaken or compromise structural integrity. Representatives of several tank companies indicated during the investigation that they believe that the better practice when dismantling tanks is to cut through the center of the welds, but that many contractors eschew this method because the need to remove gouges or make other corrections in the old weld material left on both sides of each cut requires time-consuming repairs.

Several other aspects of the dismantling job bear noting. Once the metal sheets were actually removed from the structure, they were laid on the ground to have the remainder of the exterior insulation removed. Since use of the small, manual tool to scrape the insulation off large sheets would be extremely laborious, a small, rubber-wheeled front-end loader with a blade was used instead. The bulldozer was driven onto the sheets and the insulation was stripped by the blade. One member of the work crew told investigators that the weight of the bulldozer flattened out some of the "roll" or curvature of the thinner shell sheets.

An incident consistently recalled by the STC employees at Whiskey Island was the overturning of the crane, or "cherry picker," being utilized in the dismantling. The outrigger supports for the crane apparently slipped on some wet soil, causing the apparatus to fall onto several sheets already removed from the shell of WI-16. Although Randy Fritchman denies that any tank sections were damaged as a result of this accident, another employee insisted that perhaps a dozen sheets were dented or bent fairly seriously. These plates had to be beaten back to their approximate original shape with sledge hammers.

Finally, there is also disagreement about the manner in which the steel plates were transported from Ohio to Floreffe. The accepted industry practice is to place wooden blocks or braces between sheets, at the ends, to maintain the curvature during transportation. STC trucks and employees hauled the dismembered WI-16 from its old home to its new one and Skinner, although not present at Whiskey Island at all, claims that his company policy is to brace the tank sheets. Randy Fritchman and other workers claim the sheets were appropriately protected during shipment. Again, however, one of the work crew expressly stated that no such precautions were taken and another participant was unable to recall the use of any blocks or braces, and did not believe they had been utilized.

Walters, the Ashland project engineer, says he did not observe the work at Whiskey Island at all during the five weeks of dismantling activity. Randy Fritchman believes that Walters did visit, but Fritchman had also encountered Walters at the Airborne Express job and may be confusing the two. In any event, Walters did not extensively oversee the STC work on WI-16 during this phase. Walters claimed that he was regularly kept apprised by Whiskey Island Terminal Manager Charles DeFranco of the progress. In fact, Walters recalls having learned of the crane incident

from Defranco, but did not know that it had struck any steel sheets and did not inquire of STC about the event. Similarly, Walters was not aware of the procedures STC followed to cut down the tank and was unaware of its practices regarding loading the sheets onto trucks for transport. Walters did not know if any Ashland representatives observed the loading of the steel. While Walters did not prepare any written reports tracking the course of activities, he claimed to have made oral reports to Paul Stringer and Jim Ross based upon his updates from DeFranco.

Randy Fritchman remained at Whiskey Island until the last truckload of WI-16 departed. Sometime during the week of June 16, 1986, the work in Ohio concluded and he rejoined the remainder of his tear-down crew, most of whom had already travelled to Floreffe. There they had joined with other STC employees, on-site since late May, who were working on a separate project to install a new bottom in the Floreffe Terminal's tank number 1332, a relatively small gasoline storage tank.

E. The Fire Marshall Permit

The terms of the contract with STC notwithstanding, Walters believed that his responsibilities as project engineer for the Tank 1338 job included securing the necessary permits. Consequently, some time after the signing of the contract with STC, Walters contacted the Pennsylvania State Police Fire Marshall's Office in Harrisburg to inquire about the necessary construction and/or safety permits for the tank which was to be reassembled. Walters was advised that since the construction was to occur in Floreffe, in Allegheny County, responsibility for issuing permits was with the county Fire Marshall's Office. Subsequently, Walters contacted that office sometime in mid-May of 1986. Walters recalls speaking by telephone with a person he believed to be either the fire marshall or assistant fire marshall about the proposed plans. Walters was told that he needed to submit a letter describing the site of the tank and attach a drawing showing its dimensions and its relationship to other tanks, roads, and property lines.

Accordingly, Walters sent a letter with a photo and a drawing on May 15, 1986, to Charles Kelley of the Allegheny County Fire Marshall's office presenting the information he believed had been requested. The letter concluded by asking Kelley to inform Walters of any additional information which might be necessary to secure the construction permit. When several weeks passed without a reply, Walters claims to have re-contacted the fire marshall's office to pursue the matter. At that time, he states, Walters was informed by someone, whose name he does not know, that the May 15 letter was satisfactory and the permit would be forthcoming. Based upon this, Walters concluded that the permit had been approved. He informed other Ashland officials of this progress at a weekly staff meeting. A May 28, 1986, weekly activity report from Stringer to Raiche recites that "The Fire Marshall permit is approved."

Representatives of the Allegheny County Fire Marshall's Office agree with only limited portions of Walters' account. Charles Kelley, who is in fact now an inspector for the office, recalls talking to Walters in May of 1986 about a tank construction project in Floreffe. At that time, Kelley was serving as the acting fire marshall. Kelley does not recall any further particulars of the conversation, but remembers receiving the May 15 letter from Walters about the oil storage tank. Kelley believes that he then followed the standard office procedure in response to such an inquiry, which is to instruct his secretary to mail Walters a copy of the county permit application form and fee schedule, as well as a set of instructions detailing the county codes and requirements. Neither Kelley nor the secretary have a specific recollection of forwarding these materials to Walters, but they knew of no reason why they might have deviated from the routine.

Kelley received no further response from Walters or Ashland about this project. As a result, he remained unaware that new tank 1338 had been constructed at Floreffe until January 2, 1988, when he learned precisely at the same moment both that the tank existed and that it no longer existed. Kelley vehemently denies approving, either orally or in writing, a construction permit for new 1338. He does not recall more than one telephone conversation with Walters. Inter-

views with other members of the Fire Marshall's office failed to identify anyone else who spoke to Walters about the construction permit. Fire Marshall Martin Jacobs stated that it was his express policy that his office not grant any oral approvals for construction. Jacobs, however, assumed office and instituted this policy after these events.

Walters concedes that no written permit was ever received by Ashland. He explained that he was not troubled by this at the time since, in his experience, some approvals are communicated in the form of a letter rather than an actual document which carries the term "Permit" on it. Walters' explanation, however, does not account for the fact that no such letter of the kind he envisions was ever received by APC. Nonetheless, Walters indisputably did notify his superiors at the time that the necessary permit had been approved. Whether he had one conversation or two with the county officials, Walters apparently concluded sincerely but incorrectly that the permitting requirement had been satisfied.

F. The New Tank Foundation

Before WI-16 could be re-erected on the site of old 1338, a new tank foundation or base needed to be designed and built. Walters assumed the responsibility for preparing the foundation drawings because of a backlog of other work in the Facilities Engineering Department. Although Walters was not formally educated in college as an engineer, he believed that his many years as a draftsman for Ashland Petroleum Co. qualified him to draw a tank foundation. In doing this work, Walters consulted with Robert Cruickshank, the manager of Design Engineering, Refinery Equipment Division, who was the organizational equal of Stringer, Walter's supervisor. Walters received a design sketch from Cruickshank. Utilizing this design, Walters prepared a foundation drawing.

Although he worked with Cruickshank and possibly others from Design Engineering, Walters provided them with no information about the soil composition below the area of the tank base and did not remember if he furnished data on the load or bearing capacity of the soil. For his part, Cruickshank initially denied playing any role whatsoever in the foundation design. Subsequently, however, he acknowledged that he prepared a design sketch for the foundation which Walters then utilized. Cruickshank had no recollection of how he came to prepare the design, or what information he relied upon in drawing it. He explained that it was possible that he prepared the sketch not by performing calculations regarding soil capacity but simply "by eyeballing" the design based on his experience.

Cruickshank stated that he personally preferred a concrete ringwall foundation but that Walters' actual foundation drawing, which Cruickshank admitted was faithful to the sketch he had provided, did not employ such a detail. Cruickshank could not explain why the crushed stone foundation that Walters drew, which is not the standard Ashland crushed stone design, was utilized. Although Walters was aware of a wetness problem at the tank location, and addressed it in his final contours and grading plans, Cruickshank did not recommend any density for the clay fill in recognition of this. Walters, on his own, specified the necessary density. Finally, Walters' design called for a special geotextile fabric to be placed between the clay fill and crushed stone. (Figure 4 is a copy of Walters' drawing.) Walters stated that this material was included upon the suggestion of Cruickshank. However, Cruickshank, while acknowledging that the geotextile fabric is effective in keeping water from accumulating underneath the tank and preventing rocks from protruding into the clay fill, said that he would not have recommended its use on his own initiative. The idea, he claimed, must have come from someone else. (Photo 7 shows the geotextile material exposed after tank collapse.)

On May 27, 1986, Walters issued a request for bids for construction of the tank base pursuant to the plan he had prepared. According to a handwritten note from the Ashland files, Zimmerman Excavating, Inc. ("ZEI") of Clairton, Pennsylvania, submitted a bid of $33,250.00. ZEI was on the Ashland Petroleum Company qualified bidders list, and had previously demonstrated its insurability. According to Ralph Zimmerman, one of the two brothers who operate ZEI, his firm had been a qualified participant for Ashland contracts for some ten years. According to George Morgan, the Floreffe terminal manager, ZEI had done

work at the terminal before. Morgan believed he had notified ZEI about the bid opportunity in response to a request from Walters to solicit local contractors for the base construction. Walters thought he had received other bids, but could not specifically identify any. Although Walters was aware that ZEI had never constructed a tank base before, he selected them because of their earthmoving experience. As a result, on June 18 Walters forwarded to Robert West an AFE in the amount of $36,000 to cover the actual base construction activity.

The dismantling of old 1338 at Floreffe began on approximately June 16, 1986, and was carried out by two crews from STC. One crew comprised Randy Fritchman and several of the workers previously involved in the disassembly of WI-16, and the other crew consisted of foreman Leonard Fritchman and the five or six workers who would eventually re-erect WI-16 as new Tank 1338. This second crew had already been on site for several weeks constructing a new floor for another tank.

The reassembly foreman, Leonard Fritchman, was first hired by STC in approximately 1981 as a welder's helper. He shortly progressed to welder and, in 1985, foreman. He has been involved, by his own reckoning, in more than 100 tank erection and dismantling projects for STC. Some of these jobs had involved other Ashland Petroleum Company projects. He received his training in welding and construction practices through on-the-job experience with STC. He had been recertified as a welder most recently prior to Floreffe in 1985 to satisfy another customer. Fritchman claimed that he was certified to weld on any type of metal.

The removal of old 1338 took approximately two to three weeks and was completed by the end of June. The metal from the removed tank was given for scrap to Elmer Holmes, a Turtle Creek, Pennsylvania, welder and fabricator. At this point, the STC crew surrendered the site to ZEI for preparation of the new base.

The precise manner of constructing and testing the new foundation once old 1338 was removed warrants close examination. ZEI subcontracted to Solar Testing Laboratories ("STL"), an Ohio firm with a local office in Pittsburgh, responsibility for testing the foundation preparation for moisture content and compaction. On July 2, 1986, Kevin Wiley of STL visited the tank site to examine the conditions. Although subsequently George Morgan stated that he was not aware of any water or drainage problems in the area of old 1338, Wiley reported that on July 2 the "[A]rea to be filled...was found to be covered with puddles and a thin layer of mud." He did further note that the underlying soil appeared to be stable and well-compacted. Walters, apparently aware of this surface drainage problem, required in his plans that ZEI raise the foundation and regrade the dike area.

Wiley met on July 2 with Ralph Zimmerman at the site to discuss the project. According to Wiley, they then consulted with another man in the Ashland terminal office whose identity Wiley does not know. Zimmerman does not recall accompanying Wiley to the office, but believes Wiley met with Morgan there. Wiley learned that neither of these individuals yet knew, as of that date, precisely what kind of work on the base was required. Although some specifications were contained on the drawing Walters had provided with the original bid description, ZEI was not comfortable with the degree of detail offered by the legend on the drawing. The man in the terminal office—presumably Morgan—placed a telephone call and then informed Wiley and the other that the tank base area would be proof rolled and Standard Proctor density tests would be performed on the clay fill imported to the site. Proof rolling involves making sufficient passes with an approved roller to insure that there is no moving or "pumping" of material beneath the wheels of the roller. Standard Proctor is an analytical compaction technique which determines the relationship between moisture content and density of soils. Both address or measure the degree of stability necessary for structural foundations.

These requirements, telephonically communicated, were substantially the same as those contained on Walters' original drawing. Other than this information, ZEI had no technical details provided to it regarding desired construction techniques. Zimmerman claims that he never saw a copy of API-650 nor examine its Appendix B, which describes recommended practices for foundation construction.

Morgan does not specifically recall participating in a telephone call to discuss foundation specifications. He was aware, at the time of the work, that some kind of tests would be done by STL upon the completion of sections of the foundation. When ZEI reported to Morgan that a definable increment, or lift, had been completed, Morgan was to notify Walters of this. Walters or ZEI would then call in STL for the necessary compaction testing.

Using material from a borrow area a short distance away, ZEI began constructing the new foundation for 1338 the first week of July, 1986. Although some controversy arose in the local press, after the tank failure, about ZEI's alleged lack of necessary equipment to properly compact the base, Zimmerman has documented his rental of the appropriate static rolling equipment from another local contractor. Ralph Zimmerman indicated that heavy rains required an interruption of work for approximately one week between completion of the second and third lifts. Walters confirmed that this delay occurred, and that he knew of it at the time. At least two APC progress reports from the period identify delays attributable to these downpours.

As each lift was completed, representatives of STL were summoned by Zimmerman to conduct compaction and density tests. Several different locations of each lift were examined by STL. Characteristically, a number of test areas failed to meet the project specification of 95% compaction. For example, the first lift was tested by STL on July 8, 1986, in eight different places. Five of these tests revealed compaction of less than 95%. The STL inspector surmised in the official report that these failures were attributable to high moisture content resulting from poor drainage on the job site. Similarly, four of seven test areas in the second lift failed the 95% compaction standard in a July 17, 1986, STL inspection. Testing of the third lift on July 23, 1986, revealed that five of eight locations were below 95% compaction.

It was not at all unusual that individual lifts displayed areas of initially inadequate compaction. The curious aspect of this phase of the project involves the Ashland oversight and response to these individual defects. According to Zimmerman, Terminal Manager George Morgan was present for each STL testing event. Zimmerman believed that Walters also attended some of the tests, but Walters denies ever being present. Walters claims to have monitored the work through telephone calls with Morgan and Zimmerman. Morgan, for his part, agrees that he was present for the STL tests but maintains that he had no understanding of or experience with the nuclear density testing being conducted by STL. In fact, Morgan denied realizing that any lifts had failed these tests, even though he was present for the specific instances recited above.

Walters and Morgan agree that Morgan had no responsibility to approve or supervise the foundation construction. Walters' recollection, at the time of the investigation, was that Zimmerman had assured him as the work progressed that all wet or soft spots were corrected and that this was reflected by STL records. Unfortunately, Walters' recall is not entirely consistent with what in fact occurred. Although the STL inspection reports consistently recite that failed areas of lifts "will later be rerolled and retested," that did not actually occur. According to Zimmerman, he removed soft or wet spots within about twenty-four hours of STL testing and replaced them with new fill which he compacted. The corrected areas, however, were never retested by STL. STL and Zimmerman agree that the testing concern was not summoned back to the site to re-examine a lift following corrections. Rather, defective areas were corrected and work then proceeded directly to construction of the next lift. The subsequent lift would be examined in another series of tests by STL. Zimmerman claims that Morgan was present when some of the soft spots were repaired and that, in all cases, Zimmerman proceeded to subsequent lifts without STL retesting with Morgan's approval. Morgan agrees that some corrective work was done following STL testing, but disputes the assertion that he authorized ZEI to proceed without specific retesting. He claims that ZEI could move to upper lifts only after completely successful testing by STL. Walters apparently remained oblivious of the practice that ZEI followed, whatever its on-site imprimatur may have been.

The final sub-grade was examined and approved by STL on July 25, 1986. Walters approved payment to ZEI of $33,250.00 for this work in early August.

G. Construction of 1338

Members of both Leonard and Randy Fritchman's crews remained in the Floreffe area for some time during construction of the new base by ZEI. However, the slow progress of that work, hampered as it was by heavy rains, eventually resulted in all the STC employees departing the area by mid-July. Some went with Leonard Fritchman to another STC job site in Ohio; others moved to different STC projects. Leonard Fritchman and his crew eventually returned to Floreffe on approximately August 11, 1986, to resume work on the reconstruction phase of the 1338 project.

Fritchman supervised six STC workers during the reassembly of the components of WI-16. Fritchman's main point of contact with APC was Robert Walters, the project engineer. Walters provided Fritchman with a diagram for the new tank bottom which was to be constructed for 1338, and also described the fittings and connections to be attached to the tank. Walters also visited the site approximately four times during the construction to review the work. No APC inspector oversaw the project on a regular basis, however. Terminal Manager Morgan would routinely observe the activity, but his brief was limited to insuring that the STC crew appeared on a daily basis and was working in a safe manner. Morgan provided oral reports to McIntosh and Walters but was not responsible for submitting any written progress reports. Morgan and Walters both agree that Morgan — the person on-scene daily — had no authority or responsibility to inspect the quality of the work. Morgan, in post-collapse interviews, described his involvement as very limited. He insisted that he did not ever know the last name of the crew foreman. As will develop, others recall Morgan being less detached than he claims. One STC worker saw Morgan at the construction site every day, shooting dozens of photographs of the progress.

At the time of the project, Walters was not aware that APC had a written welding policy for steel oil storage tanks. Walters admitted that he knew very little about welding himself, but felt no on-site APC inspector was necessary since he believed STC to be a reputable company. Walters' somewhat disengaged style of oversight may in fact have prevented impasses with STC over procedures since Fritchman stated, during the investigation, that he believed he had no obligation to entertain comments or suggestions from APC about erection procedures; APC was entitled only to be told the procedures that the Skinner Company intended to employ.

Fritchman and his crew first constructed a new floor for the tank on the foundation pursuant to the express terms of the contract with APC. Using steel plates provided by STC, they "tack" or preliminarily welded all the plates together and then, before proceeding to the first ring of the shell, returned to fully weld a doughnut-shaped portion of the floor measuring approximately three feet from the edge toward the center. Fritchman recalled one small uneven segment of the bottom which he deemed too insignificant to repair at the time. In later statements, STC maintained that this spot flattened out as remaining plates were welded together. According to Fritchman, these remaining bottom plates, located from the inner edge of the doughnut to the center, were welded together during slow periods due to weather or when extra workers were available. The practice described by Fritchman, incidentally, appears inconsistent with an STC "unwritten policy" related by Larry Skinner. He said that shells were not connected to floors until at least 80% of the floor welds are completed.

Fritchman and his crew moved to reassembly of the first ring, or course, of the tank following completion of the doughnut portion of the new floor. The procedure for putting this level together, as well as subsequent ones, was relatively straightforward. Relying upon the markings made upon the individual sheets during dismantling, the crew would identify the order in which plates from a common level fit together. Before plates would actually be connected to each other, an arc gouger on the thicker plates and a grinding tool on the thinner plates were utilized to clean their edges. Welders from the job contradict Skinner's claim that the edges of the sheets were beveled for rewelding. No effort was made to remove old weld material or sandblast clean four inches of each plate in conformity with Nichols' original recommendation. According to one STC worker, cleaning the edges of the old welds repeatedly revealed extensive porosity and defects

in them. These conditions were examined, he claims, by Fritchman and Morgan. Fritchman maintained, according to this account, that these were latent flaws and not the responsibility of STC. Morgan invariably elected not to request corrections of the defects in the old welds.

Following preparation the plates were fitted together in place in the tank shell using the match-mark numbers. Metal fasteners, called bullpins, were used to hold the plates together until vertical and horizontal tack welds were made. The preliminary arrangement was checked for levelness, the tack material was chipped out, and then final vertical and horizontal welds were made. Finally, the workers moved to the inside, where they gouged out the weld which penetrated from the other side before completing a final pass. After each pass, the weld was ground and buffed smooth. With the completion of each course in this fashion, the scaffolding was moved up to the next level. Succeeding courses were realigned with each other in their original orientation based on marks made during dismantling. Horizontal welds between tiers were performed after the verticals in each tier were completed.

Fritchman and Larry Skinner agreed that STC did not have any written policy concerning the kinds of welding rods to be used on different parts of tanks, or what amperage to use in applying the weld material. It also did not have written policies about limitations imposed upon welding based on climatological factors such as cold, precipitation, or winds. There was no written policy about protection or maintenance of welding rods before use; Fritchman stated that rods were stored in a house or shed on site to keep them dry, but they were apparently not warmed or heated before being used. Again, as with other issues, it was Larry Skinner's belief that good welders "know" the requirements and limitations of their trade.

The reassembly of the tank as new 1338 appears to have been as uneventful as its dismantling as WI-16. Larry Skinner visited Floreffe once, after old 1338 was torn down but before reconstruction began. Otherwise, Skinner based his knowledge of the construction upon weekly telephone reports from his site foreman. One section of the bottom ring needed to be replaced because a hole had been cut in it in Ohio to allow cleaning of the inside of the tank prior to disassembly. A new sheet was provided, at a cost of $2200.00, by Elmer Holmes. Fritchman and Larry Skinner each recall that the intermediate rings did not always register perfectly level when measured. Skinner believes this occurred only once; Fritchman recalls it "a couple of times." In any case, they agreed that the cure was to lift up the shell and floor plate with available equipment and then level it by shifting stone to correct the problem. Finally, STC installed two sumps into the floor of the tank. These sumps were 24 inches in diameter and extended into the foundation for one foot.

According to invoices that STC submitted to Ashland as the work progressed, the bottom and first rings were completed by August 25, 1986. The second and third rings were finished approximately two weeks later, and the remaining courses of the six ring tank were finished by October 3. The roof was installed by October 20, and various other appurtenances, gauges, flanges, and the previously mentioned sumps were completed during the next month. (An example of a roof structure is shown in Photo 8 and an example of a shell opening fitting is shown in Photo 9). A November 21, 1986, invoice to APC for payment recited simply "Tank is finished at Pittsburgh Penn."

H. Leak Testing by STC

Controversy begins to creep in, however, over the nature and extent of repairs which might have been made by Fritchman or his crew in the old, remaining weld material on the tank plates. Fritchman stated that there were only two instances in which defects or flaws in the old weld were uncovered during beveling and preparation of the edges. These occurred, he recalled, in a vertical seam, early in the job, in the first course. They were repaired by STC workers by gouging out the old weld and rewelding the seam in the area of the flaw. An STC welder who worked on the construction of Tank 1338 claims, however, that a greater number of repairs to old welds were made at the conclusion of the job. These repairs, including some in the second or third ring, were made following an X-ray examination of the tank.

Another worker, as noted previously, describes extensive flaws in the old welds which were ignored.

Efforts to ascertain the kinds of leak and integrity testing performed by STC personnel on the tank during or shortly after its construction engender controversy of a more substantial nature. About one procedure, the vacuum test, there is little dispute. Provisions of API-650 require that completed tank bottoms be tested for leaks by the application of a vacuum to all the welds. This procedure is performed by first brushing 30 inch segments of seams with a soap film solution or linseed oil. Then a metal testing box, six inches wide by thirty inches long with one side a glass window and its opposite open, is sealed against the tank by a gasket along the open bottom. A vacuum is drawn on the box and the weld seam examined; the presence of porosity in the seam is indicated by bubbles or foam caused as air is sucked through the seam. A tight, complete weld on these bottom seams will not be porous. (Figure 5 is a sketch of a vacuum box.)

Leonard Fritchman confirmed that the vacuum test was performed along 1338's bottom. He recalled the test, which took an entire day, being done approximately in the last week of construction. Fritchman said that perhaps two welds, located towards the center of the bottom, needed to be ground out and replaced. After making these repairs, Fritchman retested these seams and observed no bubbling. Neither Walters nor Morgan dispute that this procedure was carried out. Fritchman claims that Morgan was in fact present for ten minutes during the actual testing. Morgan's recollection, while somewhat less precise, was that he was specifically aware of the test as it was being conducted.

Leonard Fritchman also stated that a second test, the diesel penetrant test, was performed on the entire shell of the tank. This test differs from other leak checks, such as the vacuum box and the hydrotest, in that it involves no pressure or "head" to push the tracer liquid through possible voids or gaps. According to Larry Skinner, this procedure is routinely performed by STC on all tanks it constructs. As explained by Fritchman, the tests were conducted as the plates were welded together. A worker with a five gallon spray bottle would apply diesel fuel, a highly penetrating oil, to the inside seam after that was welded. Then, the fuel would be sprayed on the outside seam after that weld was applied. In each instance, Fritchman placed himself on the opposite side to search for indications of penetration of oil through the weld. Fritchman stated that Morgan observed this procedure early in the construction and inquired of its significance. He also believed that Walters visited once while a penetrant test was underway. A former STC employee agrees that the test was done on all of 1338, as each weld was completed. As a final note, Skinner stated to Ross that diesel penetration was done on the entire tank when Ross called him to inquire about testing, after 1338 collapsed.

Morgan, Walters, and even another STC employee dispute the claim that a diesel penetrant test was done on the entire tank. Morgan does agree that liquid penetrant examination was performed, but only after the construction of the first course and only to the weld seams connecting the bottom plate to the shell. Morgan knew about this because he observed diesel fuel on the ground outside the shell of the tank — apparently overspray — early in the construction and inquired about the source of this spillage. He was then told of the testing procedure which had been conducted. Morgan stated, however, that no other penetrant testing was done. Similarly, Walters was specifically aware only that a penetrant test was done on the shell to base connection. He claims to have been expressly advised about this test by STC personnel, although he cannot remember if it was specifically Fritchman who told him. He does not recall being present for any such testing. No one advised him, however, that testing of this type was done beyond the first course and Walters does not believe that it was. Finally, an STC employee who worked on the entire reconstruction project at Floreffe stated that the penetration test was performed only on what he called the "corner round," or shell to base plate connection.

It remains unclear why STC performs a whole-tank test of this sort. The relevant provisions of API-650 make the manufacturer responsible for hydrostatic testing. Nonetheless, STC did not believe that it was responsible for performing a water test on the tank to check for leaks. There is no requirement in API-650 that an

oil penetrant test be performed on tank weld seams. Within a section describing the standards for testing tank shells, the penetration method is described as one of several possible alternatives to the water test, but only where sufficient water to fill the tank is not available. STC was not, however, performing the test for Ashland in lieu of a water test. Not even STC claims that Ashland requested this procedure—during, not after, construction—because of an early determination that no water test would be conducted. Moreover, the API provision addressing these testing methods establishes that each of the tests is to be performed "upon completion of the entire tank," not progressively as Fritchman claims to have done. While STC might identify a comprehensive penetration test as a method of assuring internal quality control, it would nonetheless be, as the description of the procedure suggests, an enormously time-consuming method of achieving that goal.

I. Radiographic Testing

Sometime toward the conclusion of the reconstruction activity — probably in October or November of 1986 — Walters began to make arrangements for the radiographic, or X-ray, testing of Tank 1338. Walters requested that Morgan locate an appropriate local contractor. Because ZEI already had a valid certificate of insurance on file with APC, Morgan in turn asked the foundation builder to sub-contract the X-ray work to a qualified firm. Although he does not recall how he made the selection, Norman Zimmerman eventually settled on Progress Services, Inc. ("PSI").

PSI is a family run business with three office locations. The corporate headquarters is located in Medina, Ohio, and the company maintains offices in North Royalton, Ohio and Monroeville, Pennsylvania. Margaret Becker is the corporate president and her husband, Carl J. Becker, is the vice-president in charge of operations. Their son, Carl A. Becker, is PSI's quality assurance manager. PSI describes itself as a full-service non-destructive testing laboratory, capable of conducting magnetic particle, liquid penetrant, ultrasonic, eddy-current, and radiographic testing. It performs these tests on such items as castings, forgings, and on wax, ceramic, concrete and ferrous and non-ferrous metals. The majority of PSI's work is on naval nuclear contracts. PSI personnel were not familiar with API-650 and do very little oil storage tank work.

Walters consulted the edition of API-650 available to him at APC to determine how many X-rays to order be taken. He does not recall which API edition he used, but he calculated that the construction standard required 40 pictures of a tank the size of 1338. He identified specifically the number of "T" welds to be checked. A "T" weld, as its name suggests, is the point where a vertical weld intersects a horizontal weld. In completing his pass, the worker must weld through or over an existing weld. The connection of these two joints creates a greater potential for structural vulnerability. (Figure 10 shows a "T" weld from another welded steel storage tank.) Walters did not specify how many of the remaining pictures should be of vertical welds and how many of horizontal welds. Since Walters did not have or prepare a roll-out (a diagram showing the entire tank in side-view as if it had been cut open from top to bottom and then flattened), he did not further identify the X-ray locations. Walters communicated this limited information about his request to either people at ZEI or to George Morgan.

Norman Zimmerman recalls telephoning PSI in this time frame and speaking to someone named Becker. He told this person that Ashland Oil needed X-rays taken of a tank and that it needed a price quoted for the job. He claims to have directed PSI to Morgan for additional details necessary to calculate the cost, and then to call him back with the price. Zimmerman believes he made a second call to PSI because the price changed as a result of the removal of scaffoldings. Carl A. Becker's recollection differs slightly. He stated that Norman Zimmerman called twice, each time stating that forty shots were needed and describing the circumstances of the tank reconstruction project. Becker gave ZEI a quote of $2,000.00 each time. The second call mirrored the first, with the exception that Zimmerman told Becker to contact Morgan for instructions about scheduling the X-rays.

Carl J. Becker recalls discussing the project in some detail thereafter with Morgan, whom he says was his sole APC contract. He claims to have

learned details from him about the project in general, the welding joint design, the tank plate thickness, and the precise number of shots for vertical, horizontal, and T-joint welds. Morgan identified PSI's responsibility as limited to taking the X-rays, developing and interpreting them on-site with regard to API-650, and discussing the results. PSI was not, under this contract, responsible for repairing welds or doing follow-up radiography. Becker, from these discussions, believed that Morgan was either an engineer or had some engineering training. Morgan recalls none of these discussions, and the level of technical sophistication and project detail in the conversation described by Becker is more consistent with Walters' role and background. Nonetheless, Walters cannot identify any such discussions about the radiography work with PSI.

In either case, Carl J. Becker and two technicians arrived at the Floreffe Terminal at approximately daybreak on November 17, 1986. He stated that he was met there by Morgan, who showed him the tank and specified how he wanted the forty X-rays taken. Morgan prescribed how many T-joints, horizontals and verticals, but allowed Becker to pinpoint exact locations himself. Becker recalls several members of the welding crew being present at this point. One of them, apparently, was Leonard Fritchmen, who specifically recalls Morgan giving the X-ray technicians directions for the location of the radiographs from a plan Fritchman believed had been provided by Walters.

Upon observing the tank for the first time, Becker questioned Morgan about the possible need to perform more than forty X-rays on 1338. He claims that Morgan advised him that forty shots were all that were necessary. Remarkably, Morgan and Walters cannot account for these particular events or discussions. Walters, as noted previously, denies using any diagram or plan to identify horizontal and vertical orientations for X-rays. Morgan cannot even recall being present during the actual radiography activity on November 17, let alone playing a significant role.

Nonetheless, Carl J. Becker described a process that date of taking several X-rays at a time, developing them, and then discussing the results with Morgan and the foreman and other members of the welding crew. He then repeated that process until he completed X-rays at 39 locations. It became too dark by then to complete the fortieth and last radiograph. Becker recalled that most of the scaffolding was already removed by November 17, but that its absence hampered him little. Almost all of his shots were taken in the lower course.

Becker reported to Morgan and the welding crew foreman that day that 22 of the 39 welds he had examined were rejectable. He left in Morgan's office a copy of his field report form, which specified the failed samples and described briefly the defects. The problems were generally due to the inclusion of slag, lack of penetration, lack of fusion, or porosity in the welds. In his discussion with Morgan and the others that day, Becker explained that these defects were in the old, original welds, not the recently completed work. Becker believed the new work was of good quality. Becker recalls a discussion on-site between Morgan and the welders about responsibility for these defects. It is Becker's perception of this conversation that Morgan was not trying to fix blame on the welders but was hesitant to effect repairs of forty years old welds due to cost ineffectiveness.

At the request of either Morgan or Walters, Carl A. Becker transmitted a letter to the terminal manager on November 25 explaining that the procedure of cutting the tank down to the side of the original weld, rather than through the old weld and then cleaning and re-beveling off the old material, had allowed the old defects to remain and be detected by the radiographs. Becker wrote, "It is my opinion that the areas which are rejectable are in the old weld and not in the weld recently done." Becker was adamant during the investigation, however, that he never deviated in any oral or written discussions from his conclusion that the welds, regardless of where the flaws originated, were rejectable.

Several ripples of minor activity were caused, more or less simultaneously, by the results of the radiographic examination. Fritchman, who was present for at least some of the discussions with PSI on November 17, claims to have immediately offered to Morgan that STC would repair the defects in the old welds if Ashland desired. Approximately three days later, according to Fritchman, Morgan advised him that the welds did not need to be repaired. Thus,

Fritchman claims that the only repairs to old welds that were made were those earlier in the job, when he discovered flaws in an old vertical seam in the first level. These were rewelded. A former STC employee, as noted previously, claims that Fritchman ordered repairs to several defective old welds after the X-rays were examined. To date, there is no corroboration of this statement. Larry Skinner, for his part, was unaware of any defects, either identified by radiograph or repaired by his crew. In public statements after the collapse, however, Skinner agreed that his crew would have been willing to make the necessary repairs for a nominal fee. Consistent with his total lack of recall about the X-rays, George Morgan has no recollection of receiving—and rejecting—this offer from Fritchman. No other APC employee recalls hearing of it.

Walters, however, did learn about the problems that the X-rays had located and recalls that he discussed the issue with Morgan. He was told by Morgan that the flaws were in the old welds and that the new welds were good.

As this was occurring, James Ross, the facilities manager for the Surface Transportation and Facilities Group, recalls making an unrelated visit to see Morgan at the Floreffe Terminal. When he arrived in the terminal manager's office, Morgan handed Ross the telephone and explained that an individual from the X-ray company was on the line. Ross then spoke to the radiographer, whose name he does not recall, who attempted to engage him in a technical discussion about the weld defects. Ross referred the caller to Walters. When he left Floreffe, Ross carried the actual X-ray film with him back to Ashland, where he placed it in inter-office mail to Walters.

Either as a result of Ross's referral or his own initiative, Walters then spoke to Carl J. Becker. Becker confirmed the explanation that Morgan had already given Walters, to wit, the flaws were in the old welds, not the STC work. Walters also reviewed the November 25, 1986, letter from PSI. Upon receiving the actual film of the welds, Walters states that he took two pictures to show Willis Steele. Steele worked in the Inspection Department, under Elwood McCoy. According to Henry Raiche, the present Director of Engineering for APC, it was the responsibility of the Inspection Department to read and interpret X-ray film presented for its review. Nonetheless, according to Walters, Steele refused to examine the film because there was no roll-out sheet available which would show locations of the X-rays. Steele expressly rejects this account. He has maintained that the first time he saw X-rays from 1338 was after the collapse, and not anytime before. Paul Stringer, Walters' superior, never learned of the problems with the X-rays at this time, either.

In Walters' chronology, he returned from his failed effort to secure assistance and interpretation about the X-rays from Steele and decided to simply file the film away. He determined that no corrective action about the weld defects was necessary for several reasons. He believed that the standards from API-650 which the welds had failed to satisfy did not apply to old welds. Further, he knew that the flaws were located in old welds which had held for some 40 years at Whiskey Island. Moreover, he may also, by his own subsequent explanation, have believed that he enjoyed an additional safety margin in service at Floreffe since the No. 2 diesel fuel would have a lower specific gravity than the prior product, No. 6 heating oil. Stringer, from the vantage of hindsight, claimed that the acceptance of defective welds, wherever they existed, was a bad practice. He maintained that, had he known, he would have insisted on their correction.

Walters has recently speculated that he probably telephoned Larry Skinner to discuss the faulty welds, but he cannot recall a specific conversation with the tank builder. Skinner denies having learned about any defective welds. Conversely, Walters does not believe he discussed his decision not to pursue corrections of the flaws with Ross. The latter, however, expressly recalls a conversation about the X-rays with Walters soon after he returned from Floreffe with the film. Ross stated that Walters called him and explained that the discontinuities were in the old welds, which had held for forty years. Ross also provides some confirmation of Walters' claim that he sought advice about interpretation of the X-rays; he says that Walters mentioned taking the X-ray file to the Inspections Group for their review. Ross could not recall if Walters said anything more about this effort to enlist additional assistance.

Ultimately, Ross says that Walters advised him that he had decided to accept the welds as they were. Ross admits that he did not protest this decision. He did not believe he had the expertise to second-guess Walters. It was also his understanding that his organizational segment — Trucks and Terminals — was simply the "client" of Facilities Engineering. In Ross's opinion, this corporate relationship absolved him, or his section, of any responsibility and denied him any authority to challenge these kinds of decisions.

J. The Water Test

Ashland's original goal was to have the new Floreffe tank in service by the autumn of 1986. Because construction of the main structure of 1338 did not conclude until the middle of November, APC management accepted that the tank would not have the necessary pipes attached before much of the 1986-1987 heating season was finished. Elmer Holmes had been the low bidder for this work, but because of his other commitments to Ashland he projected that he would be unable to begin working on connections for 1338 until March of 1987. Since the earlier delivery dates of the higher bidders were still past peak fuel season, APC elected to award Holmes the contract and wait for his availability.

The remaining significant stage of the 1338 project — the water test of the completed tank — is probably the most controversial and, from a decision-making standpoint, ambiguous. Although only Walters, Ross and Morgan were involved for APC, a pronounced lack of certainty about how events transpired has been engendered by the substantial inconsistencies in their statements. These inconsistencies exist not only between the various individuals' accounts, but also within the same employee's story from occasion to occasion. In one instance, an employee substantially changed his rendition of events in the middle of his statement. The following narrative, therefore, will unavoidably lapse into minutiae from time to time in the interest of presenting as much detail as possible.

Project Engineer Walters had begun investigating methods to hydrostatically test the tank virtually as soon as the contract with STC was signed. Although Walters was aware of no written APC policy requiring such tests, he believed that API-650 mandated a full water test of all tank construction. He recalls directing Morgan in the summer of 1986 to contact the local water supplier, which was West Penn Water Company, to determine its capability and price. He also recalls learning soon after from Morgan that there was no problem with availability from the municipality. In fact, Walters knew that fire hydrants were available at Floreffe. He gave the cost estimate for the water to Ross, the facilities manager.

Ross' recollection of these events improved dramatically over several encounters. He initially stated that he had no responsibility for and minimal involvement in any testing of 1338. He had simply been advised, he claimed, in October 1986 by Walters that there was "some trouble" getting water to fill the tank in a timely fashion. He maintained that he learned from Walters at that approximate time that APC would simply follow the contractor's advice on the question of tank testing. Finally, he believed in late 1986 that Walters told him of the performance of — but not the results from — an oil penetration test.

In subsequent interviews, Ross provided rather more texture to his answers. Although Walters' position was that he was unaware of any impediments to using city water, Ross stated that he learned from Walters that a low flow rate from West Penn Water would mean that filling the tank would require an extremely long time. Specifically, Ross says he was told that the water authority was limiting APC to a two-inch line to maintain pressure to its other customers, and was requiring that a backflow prevention device be installed on the line to eliminate the possibility that water might somehow reverse its flow out of 1338, after picking up residual contamination of No. 6 oil from the tank walls, and thereafter contaminate the municipal water supply.

West Penn Water Company ("WPWC") officials — who presumably are disinterested cameo players in these conflicts — provide some, but not total, clarification. Charles R. Thomas has been the operations manager of the Valley District office of WPWC since 1981. Thomas discussed APC's water needs for filling a tank only with George Morgan. He remembers receiving a call from Morgan, who inquired about the availability

and price of water to test a newly-erected tank. Thomas advised Morgan that WPWC would require a water meter on an existing fire hose line and a backflow preventer. Morgan, according to Thomas, resisted the use of these devices and requested instead that WPWC calculate the gallonage which would be used from the tank's own volume measurements. Subsequently, Thomas directed a billing clerk to calculate the price for APC. He also discussed alternatives to the meter and backflow device with Kenneth Kohley, the District Manager of the Valley District Office where Thomas worked. Kohley recalls this incident and remembers telling Thomas to try to accommodate Ashland's requests to find substitutes for the meter and backflow device. Kohley also recalls that he and Thomas agreed that the almost 4 million gallons of water needed were available.

Soon thereafter, Thomas contacted Morgan and gave him a quote of $4,884.38 for 3,440,000 gallons of water. He also told Morgan that Ashland could dispense with the hydrant meter and could use the air gap method in lieu of the backflow device. Thomas described the "air gap" method as nothing more than filling the tank from the top by hanging the hose there, and insuring that the water level never reaches the incoming water nozzle. Although Thomas does not independently recall when these conversations occurred, he produced during the investigation a WPWC form captioned "SERVICE ORDER" which related to this water inquiry. The form, dated 5/17/86, contains the words "Floreffe" and "Ashland Oil," as well as the figures 3,440,000 and $4,884.38. It has Morgan's name and a Floreffe terminal phone number on it. Both billing clerks involved in preparing and monitoring this form for WPWC specifically recall it from May of 1986. Although he had no independent recollection of the date, Thomas agreed it was from this form that he provided his price quote to Morgan.

Thus, according to WPWC, Ashland's local contact — Morgan — knew as of approximately May 17, 1986, that ample water was available and that the water utility was amenable to providing it in an efficient and essentially unrestricted manner. Thomas' account, however, introduces yet another mystery: why did APC provide WPWC with 3.4 million gallons as the figure for a full tank, when 1338 had a capacity of almost four million gallons?

Terminal Manager George Morgan was able to provide some clue to this — but only to this — mystery. Morgan agreed that he was told by Walters to investigate the availability of municipal water to test Tank 1338. Walters, according to Morgan, explained that the test helped ensure that the tank was able to hold its product to its full capacity, and to test the base for settlement. Morgan says that Walters provided him the 3.4 million gallon figure to use, and explained to him that a full tank of oil (presumably, No. 2 diesel fuel) would represent the equivalent weight of the smaller volume of water in as much as water had a higher specific gravity. Morgan's account of his discussions with Thomas differs, however, in one significant way. Morgan recalls resisting the idea of a back flow device and water meter based on directions from Walters. He does not, however, recall Thomas acceding to this resistance soon thereafter. It was Morgan's belief that it was desirable to get the tank in service as quickly as possible. The lengthy tank test APC faced based on the utility's restrictions would delay meeting that goal.

There is one other critical distinction between Morgan's account and all the others. During his interview, Morgan initially agreed that these events occurred in 1986. About midway through the interview, however, Morgan reconsidered his statements and changed his position. He thereafter maintained that his contact with Thomas of WPWC, notwithstanding the utility's documentation and the statements of its staff that this interaction was in May of 1986 and notwithstanding the recollections of Ross and Walters, took place in the spring of 1987. He denied any involvement with the water test efforts before that time, insisting that it was not until then that Walters had solicited his assistance. Morgan claimed that all testing efforts for Tank 1338 had been postponed when the winter of 1986 arrived and the tank was not yet in service.

It may be useful to summarize the tangled threads of the participants' accounts thus far. A curious parallel emerges. Morgan was the sole conduit for information to Walters from WPWC, yet Morgan's understanding was different than theirs, even though Walters and WPWC some-

how agreed with each other. Similarly, Walters was the channel for information from Morgan to Ross, both of whom appeared to have the same belief. This was not, however, the same understanding as possessed by Walters. More specifically, Thomas and WPWC say that as of May, 1986, they had advised Morgan that sufficient water was available without restrictions. Walters says he knew essentially the same thing. Ross believed at some point in 1986, ostensibly from Walters' information, that the availability of municipal water was significantly limited, at least as to the rate of flow into the tank. Morgan's claim is that he did not know about any of this until the spring of 1987. At that time, his understanding was essentially congruent with, albeit more recently acquired than, that of Ross.

Walters and Ross agree, more or less, that they continued to discuss the issue of water testing the tank throughout 1986. According to Walters, in the fall of 1986, he began examining the possibility that a pump could be used to convey water from the nearby Monongahela River to fill 1338 for testing purposes. Walters cannot now account for his efforts to explore alternatives since he believed at the time that there were no problems associated with the use of municipal water to fill the tank. Ross, however, believes that the aforementioned backflow device and small hose flow restrictions were the triggers. Since these requirements, as Ross understood them, would greatly increase the time necessary to fill and test 1338, he and Walters agreed to explore the use of a pump.

Unfortunately, Walters learned that only non-combustible diesel pumps could be used at the site because possible sparking near flammable materials from gasoline-powered pumps would be unsafe. Diesel pumps with the capacity Walters needed, however, to deliver large volumes of water from the river to the tank efficiently were so little in demand that he could not find one to rent. Walters found the cost of purchasing the specialty pump for this one occasion to be prohibitive. Moreover, pumps on fuel barges employed by Ashland for delivery of product to the terminal were not adaptable to pumping water.

In his last, and more forthcoming, interview, Ross explained the backdrop against which the actual decision to omit the full hydrostatic test was ultimately made. He believed that if the test was to be performed, it was preferable to do it while the tank builder was still on site so that any leaks which were discovered could be repaired. He also believed it was better to test before pipes and other fittings were attached. Finally, Ross was of the opinion that a cold weather test was better than a warm one.

Nonetheless, Ross stated that he decided in November of 1986, when STC was still at Floreffe, that APC would not conduct a full-capacity water test. He explained that it was his understanding at the time that an oil penetration test had been done on the entire tank. He is not sure if he was specifically told this or simply assumed it. Regardless, Ross believed at the time that API-650 required the oil penetration test and that STC was contractually obligated to build 1338 to those standards. He believed the water test was optional and that the penetrant test alone satisfied the standard. At the time he made his decision, Ross thought that the sixth edition of API-650 was in effect. He was not familiar with the seventh edition, which was in fact applicable. (Both editions require hydrostatic testing). Ross did not, to the best of his recollection, call Larry Skinner or anyone else at Skinner Tank Company, and he does not assert that Walters told him that a complete penetrant test was performed. Ross did not witness any such testing on Tank 1338, but claimed familiarity with it from prior experiences.

Walters readily agrees that the decision to dispense with the full water test was made by Ross. He disagrees, however, about the timing. According to Walters, no final decision was made in 1986. In the spring of 1987, he renewed his efforts to find alternatives to municipal water, this time searching for what he called an air-operated pump. This too was unsuccessful. Soon thereafter, in June of 1987, Walters says that Ross decided not to fill the tank with water. Walters personally disagreed with this decision and is sure that he expressed his concern to Ross. He cannot, however, recall any specific conversations, including any where he might have discussed with Ross the factual extent or API-650 sufficiency of oil penetrant tests performed on 1338. In an interesting reversal of Ross' earlier

deference to Walters about radiography decisions, Walters explained that Ross, the representative of Tracks and Terminals on the construction project, was authorized to overrule any objections from the project engineers. Finally, Walters spontaneously sought out Task Force investigators after an interview had concluded to clarify his efforts to dissuade Ross from abandoning the water test. Walters claimed to have taken his disagreement about this decision to his superior, Paul Stringer in the relevant time frame. Stringer, according to Walters, responded that "If that's what they want to do, then that's fine."

Neither Stringer nor Ross fully confirms Walters' description of his resistance. For his part, Stringer completely denies knowing anything about disagreements about the hydrostatic test in 1986 or 1987; he did not learn until after the collapse that the full water test had not been conducted. Ross maintains that no one, including Walters, protested his decision not to fully test the tank.

Ross has acknowledged, however, that Walters reprised the possibility of a full water test when they discussed the next step. Ross claims that in the summer of 1987 he asked Walters to put ten feet of water — approximately to the top of the first ring — in the tank. Ross emphasized to investigators that this was not a substitute for a hydrotest but rather a type of fail-safe confirmation of the results of the oil penetrant test. According to Ross, oil penetration examinations often fail to identify leaks in the bottom, in the first few inches of the shell, and in the base to shell connection. Placement of the water would highlight any such problems. Additionally, the weight of the liquid would enable the tank to seat itself on its foundation and be checked for settlement.

Ross agrees that Walters, upon learning of this request, proposed doing the full water test. Ross refused because he saw no need for it. In his opinion API-650 had been satisfied and no further effort of this sort was required. Ross does not believe Walters protested further.

Walters recalls being directed by Ross to fill 1338 with water to the top of the first ring. Walters believed the water was to be left in the tank overnight. At this point, the accounts of Ross, Walters and Morgan once again converge. Morgan claims that he heard from Walters in June of 1987, only a few weeks by Morgan's revised chronology after Walters requested 3.44 million gallons, that the tank should only have five feet of water placed in it. Morgan says that the only reason for the change offered to him was that this smaller volume of water was sufficient to establish the range of base settlement.

Accordingly, Morgan recontacted Chuck Thomas at WPWC and requested that only enough water to fill the tank to five feet be supplied. Since Morgan claimed that WPWC, in his earlier contact, was requiring the flow restrictors, he is unable to account for the fact that the backflow device and hydrant meter did not remain components of the supply of water. Nonetheless, Thomas went to the Floreffe Terminal sometime in early June of 1987 and met with Morgan. They confirmed, according to Thomas, the use of the air-gap method and hung a firehose over the top of 1338. Thomas estimated that the 2 1/2" hose should have required approximately 14 hours to fill the tank to a five foot level. Extrapolating, he projected that it would have taken 4.7 days to fill tank 1338 with 3.44 million gallons of water.

There is a remarkable difference of opinion about how accurately Thomas predicted the schedule. John Gajdosik, an APC terminal operator at Floreffe, personally participated in pumping water into 1338. Gajdosik recalls a conversation between Morgan and McIntosh to the effect that a call to APC headquarters was needed to learn how to test the tank since it was the first built on-site in more than 15 years. Soon after, water was pumped into the tank to a level, according to Gajdosik, of ten feet. The precise level was read from a side gauge on the tank. He recalls this occurring in late June or early July of 1987, and requiring about two days to complete. The water was left for three to six days, and then drained over a period of some four days. Another operator from Floreffe thought placing the water in the tank required at least three days.

Morgan, remarkably, insisted that it took several weeks to place the requisite amount of water into the tank. He explained that the period was so extended because pumping occurred only during regular business hours. There is no obvious explanation for the discrepancy between his recollection of the length of time involved and

the memories of other participants. In any event, on June 9, 1987, Morgan wrote to Thomas and informed him that APC had placed 400,260 gallons, equivalent to 5' 1 5/16", in storage Tank 1338. On July 3, 1987, WPWC sent APC a bill for $802.22 for this amount of water.

K. Settlement Testing

By this time, one last outside contractor had been brought into the entourage associated with the 1338 project. In March of 1987, ZEI had sub-contracted with Gateway Engineers, of Pittsburgh, based upon Walters' request to Morgan that a surveying or engineering firm be retained to take elevation readings of the tank. Again, due to APC's requirement of a certificate of insurance, Gateway was retained under the umbrella coverage of ZEI.

Gateway's first visit to Floreffe occurred on March 12, 1987. Survey crew chief Richard J. Bove met with Morgan that day to learn the scope of his work. He was asked to take his elevation readings at the seams of the plates located at the base of the tank. Morgan explained that he wanted to see if there were any locations where the tank had settled. Morgan also told Bove that he would probably be needed four or five times, which Bove took to mean when the tank was empty, one-quarter, one-half, three-quarters and totally full. Morgan, however, did not specifically explain the specific significance of the projected visits.

Following his preliminary elevation readings that March, Bove was summoned back to the terminal by Morgan on June 11, 1987. He took new elevations on that date, which coincides closely with the June 9 notification to WPWC that 1338 contained slightly more than five feet of water. Bove, however, could not independently confirm himself that any liquid had been added to the tank.

Ross has stated that he asked Walters to place ten feet of water into Tank 1338 to test for leaks and settlement. In the communication of this to Morgan, the original request for the ten feet was effectively halved, to five feet of water. Interestingly, on August 25, 1987, Gateway was contacted for a third time by APC, and Bove reshot his elevations. By this time, the tank had been sandblasted and painted with primer. However, WPWC never received a request for any additional water from APC or notification that additional water had been used subsequent to the June 9, 1987, letter from Morgan. In fact, product inventory records for the Floreffe Terminal reveal that 1338 in fact contained some ten feet of No. 2 diesel fuel on August 25, not water. Walters knew that an elevation was taken on that date, but initially stated that he did not know the tank's contents. Subsequently, he stated that he had made the arrangements with Gateway for the third visit, when ten feet of product was in the tank. He did not explain whether this test was in response to Ross's original direction, in which case he was testing for tank leaks with petroleum product as his tracer, or simply for additional foundation settlement. Either way, neither Morgan nor Walters requested any subsequent elevations from Gateway. The four or five visits which Morgan originally posited to Bove failed to materialize. Settlement — or leak — evaluations were based upon a load of less than one-fourth of the 48 foot tall tank's capacity.

The elevation figures that Bove did derive from his three visits indicated very minor and uniform settlement. Walters and Stringer agreed that this tank movement presented no problem, although they apparently consulted no source or text as a point of reference for their conclusion.

L. Use and Maintenance at Floreffe

It was widely reported that the January 2, 1988, collapse of the tank occurred as 1338 was being filled for the first time. Those accounts were correct only in the most literal sense of the word "filled"; in fact, the tank was introduced into service in late August of 1987 and was in use continually thereafter. Specifically, on August 24 almost 800,000 gallons of diesel fuel were pumped into the tank from a barge docked at the Floreffe Terminal. Prior to this, 1338 had contained only the residue of water from the June hydrotest, and the residue from the small amount of product used to force the water out of the tank's

sumps. These two residues made up the 9-1/2" of liquid which could be found in 1338 on August 24. The first barge delivery brought the level in the tank to 10'-3 1/2". It apparently also provided the trigger for the final elevation measurements taken by Gateway Engineers the next day.

Thereafter, Tank 1338 served its intended function at the terminal as the major storage unit for diesel fuel. Less than a month after the first delivery of product to 1338, tank 1367, which had been used as a "swing" tank for diesel, was taken out of service due to the accumulation of sludge on its bottom. After September 22, 1986, only 1338 and 1334, with less than one-tenth the capacity of the reconstructed tank, were in diesel service. Between the first delivery on August 24 and the interrupted delivery on January 2, 1988, 1338 received at least 28 barge shipments of product. Its elevation fluctuated from a low of 1'-7" on October 23 to a high of 36'-11 5/8" on December 22.

After its introduction to service, the tank was subject to the routine inspection and maintenance procedures of the terminal. Terminal Manager Morgan indicated that the tank inspection practices at Floreffe did not change with the construction of Tank 1338. According to him, each tank was visually inspected daily at about 6:00 A.M., the beginning of the dispatching shift, by the terminal operator responsible for reading the tank's side gauge. No routine report or other paperwork was submitted documenting these daily inspections. Roofs and roof vents were inspected at those times when product was pumped into the tank and the operator was required to go to the roof to check the fuel level with a plumb bob.

Morgan also performed, with the assistance of terminal operators, more extensive annual inspections of the light oil tanks. In these, Morgan checked the roof and vents, the paint and sheet metal, the tank's levelness, and pumps and other machinery. Morgan also insured that the two inch rim around the bottom of each tank was exposed and capable of inspection for leaks, not covered with dirt. These annual inspections were recorded on a form for each tank and took about two weeks. Additionally, APC began a practice of performing acoustic leak tests on its light oil tanks in 1987. Tank 1338 was not inspected in that program because of its recent construction.

Floreffe terminal operators, however, depict the daily inspection regimen as substantially less vigilant than does Morgan. According to the operators, who perform general terminal functions and the inspections during gauging described by Morgan, these daily early morning tours of the tanks are much more for inventory purposes than for structural integrity concerns. Two operators forthrightly said that no specific daily inspection of tanks was performed or ordered, although they were obviously expected to report a problem if they stumbled over it. One operator allowed that the purposeful discovery of any but the most major of breakdowns was unlikely much of the year since the morning inventory was conducted at 6:00 A.M., in the dark, with a flashlight. An operator also stated that he was unaware that any roof or vent inspections were to be or had been conducted except during the comprehensive annual examination of the tanks.

M. The Tank Collapse

December and January, the middle of the heating season, witnessed wide fluctuations in the diesel fuel level in Tank 1338 as the Floreffe terminal continuously provided wholesale distribution of product to its customers and replenished its inventory. For example, the tank received a delivery of more than 1.25 million gallons on December 29, 1986, bringing its product level to about 35'-5", or just under 3 million gallons. By early afternoon of New Year's Day, 1988, the level of diesel fuel in Tank 1338 had already been sold down to slightly over 29'-10", representing a distribution of almost 500,000 gallons.

Terminal Operator Charles Bailey was requested to report to work at the terminal on January 1, 1988. Although it was a holiday, the facility was scheduled to receive a series of barge deliveries, primarily of diesel fuel for Tank 1338, that afternoon. Barge deliveries were usually made by the Pittsburgh Tug Company, and the tankerman was almost always Gary Thompson. Thompson worked for the tug company, but as tankerman he met the barge at the terminal when the tugboat delivered it and he then supervised the unloading. The tug generally departed while unloading was proceeding.

Bailey arrived at about 1:30 p.m. on New Year's Day and the first of the delivery vessels, designated as Barge A.0.C.-207, was delivered to the terminal dock by the tug Mary Claire approximately one hour later. The barge was secured and gauged and its flashpoint checked, all pursuant to standard operating procedures. Barge A.0.C.-207 was one of the larger vessels, with a capacity of almost 20,000 barrels, or 840,000 gallons. A form, called "Declaration of Inspection Prior to Bulk Cargo Transfer," was completed by both Bailey and tankerman Thompson. This document is essentially a checklist attesting to compliance with a variety of federal regulations addressing the safe transfer of oil products.

The "Declaration" recorded that the barge arrived at 2:30 p.m. A hose from the barge was connected by Bailey to the terminal's integral piping system. According to Ashland's bill of lading, the barge began pumping at 2:45 p.m. The level in Tank 1338 stood at 29'-10 3/4". Bailey monitored the side gauge that provided fuel level readings for the tank. According to Thompson, pumping generally proceeded at a rate between 1,700 and 2,200 barrels per hour.

Because of its size, A.0.C.-207 required the rest of the day and more to complete unloading. The barge was released at 1:00 a.m. on January 2, after having transferred more than 823,000 gallons of diesel fuel. The level in the tank now stood at 38'-11 5/8". Several hours later, 8,000 and 12,000 barrel tugs arrived at the Floreffe location, courtesy of the Mary Claire. After repeating the "Declaration" procedure, Barge W.B.C.-12 began unloading at 5:15 a.m. As with the first barge, Bailey noticed nothing unusual about the pumping activity.

Sometime shortly before 9:00 a.m. that same morning, January 2, Bailey was relieved by John Gajdosik, a senior terminal operator. Gajdosik added his name in the appropriate "second watch" block on the original "Declaration" form prepared earlier by tankerman Thompson and Bailey for W.B.C.-12. Gajdosik's signature was affixed at 9:00 a.m. Since the terminal was open that day for dispatching, Gajdosik was joined on the site that morning by another terminal operator, Edward Weightman, and by the office secretary. Throughout his time at the terminal on January 2, Weightman attended primarily to truck dispatching, not the filling of Tank 1338.

Before Bailey left the terminal, he and Gajdosik reviewed how much fuel could be pumped into the tank because the volume of product remaining on the two barges docked at the terminal exceeded the unfilled capacity of the 48 foot tall 1338. This was the first time in its incarnation at Floreffe that the tank was to be filled to its maximum allowable capacity and consequently the first time that such a calculation was necessary. Gajdosik determined that the maximum elevation to which the tank could be filled was the 46 foot level. This height was derived from the need not to obstruct required fire-foam safety lines, which entered the tank near its top. Gajdosik measured six inches below their point of entry and arrived at a maximum permissible fuel height of 46 feet.

In order to maximize the volume of product that the terminal could accept from this series of shipments, Gajdosik also decided to transfer No. 2 from 1338 to 1334, the other, far smaller diesel storage tank at Floreffe. Transferring directly from 1338 to 1334 was a safer procedure than having the barge switch from pumping directly into one tank to directly into the other.

As the transferring of fuel from W.B.C.-12 proceeded, another barge connected to the terminal pipe lines and began discharging unleaded gasoline into the appropriate tank, 1331. This began at 6:16 a.m. Thompson was the tankerman for this as well. The second diesel fuel barge, W.B.C.-12, completed pumping at 11:30 a.m. It had unloaded another 266,000 gallons of No. 2 into Tank 1338, bringing its fuel level to 41'-4 7/8". It also provided, through the inter-tank transfer, slightly more than 84,000 gallons to tank 1334.

The exact time at which the last barge, A.0.C.-246, hooked up to the pipeline and began transferring is harder to pinpoint. The bill of lading for this shipment states that its "begin pump" time was 4:15 a.m., which implies that it was pumping at the same time as W.B.C.-12. This is not likely to be accurate. There is no entry in the nearby block on the lading bill for the time that A.0.C.-246 first arrived, and it is therefore possible that the "4:15 a.m." notation provided this information but was simply entered in the wrong place. This is supported by the "opening" tank gauge information for 1338 entered elsewhere on

the shipping form. The "opening" fuel level is recorded there as 41'-4 7/8", the precise closing reading on the bill of lading of the immediately prior barge, W.B.C.-12, which disconnected at 11:30 a.m. Finally, in addition to his signature Thompson's entry on the "Declaration" for A.0.C.-246 contains "1200 hrs 1-2-88" in the block assigned for the time and date of transfer from this last barge.

A starting time of noon for the third barge is generally consistent with the recollection of Gajdosik, who had not been on site at 4:15 a.m. He recalls that the unloading of this barge commenced at 11:30 a.m. Between that time and 2:00 p.m., the other two Ashland employees left the site as the dispatching day ended. Gajdosik remained at the terminal to monitor the filling of 1338, which proceeded uneventfully. The temperature at nearby recording stations ranged during the day from about 16°F. to about 26°F. and the wind speed reached nine miles per hour. At 4:00 p.m., Gajdosik increased the frequency of checking the gauge on 1338 from every thirty minutes to every ten minutes as the diesel approached its maximum allowable height. As the level of fuel rose, he also began measuring its height more precisely by climbing to the top of 1338 and checking its surface with a plumb bob. At 4:58 p.m. Gajdosik made what would turn out to be his last visit to the tank and measured the fuel height from the roof of 1338. The level, based on the "closing" gauge readings on A.0.C.-246's bill of lading, stood at 45'-10 1/4", or 3,857,384 gallons of product. There were less than two more inches of fuel to be added to the tank. Gajdosik estimated this would take about fifteen minutes. He drove back to the terminal office, remaining in radio communication with Thompson, at the barge, at all times.

At 5:02 p.m. Gajdosik, located near the door of the terminal office some 650 feet from 1338, heard a noise he described to investigators as sounding like thunder coming from the area of the tank. In other accounts, Gajdosik has also compared the sound he heard to a rifle shot. He turned toward 1338 and observed the roof collapse and a cloud of mist start to form. While these brief observations by Gajdosik provide probably the best available personal description of the actual collapse, two local citizens described comparable perceptions. Shawn Mazzola was playing street hockey at the time in a parking lot when he heard a rumbling noise which he thinks lasted three to four seconds. When he looked toward the Ashland terminal, he saw a storage tank fold over and collapse and mist rise from the ground. Finally, Alva Rogerson, who lives across Route 837 from the storage facility, heard a loud rumbling which lasted approximately thirty seconds and was foilowed by a "pop" sound. She observed a wave of foam splash over the top of Route 837.

Gajdosik immediately radioed Thompson and ordered him to halt pumping. Thompson recalls Gajdosik saying, "Shut the pumps down. The tank is gone." Thompson's bill of lading for this shipment, in a block provided for remarks, reflects the interrupution in delivery with the laconic entry "Partial." Gajdosik cut electrical power to the tank area and began the process of providing emergency notifications. Alva Rogerson placed a similar notification call to the local emergency response number and Shawn Mazzola made his way to the terminal to help reroute traffic around the spill. These were undoubtedly the first corporate and personal responses to the collapse, but it is unlikely that any of these individuals could foresee the magnitude of the disaster then unfolding or the counter-measures which would be necessary in the days and weeks to come.

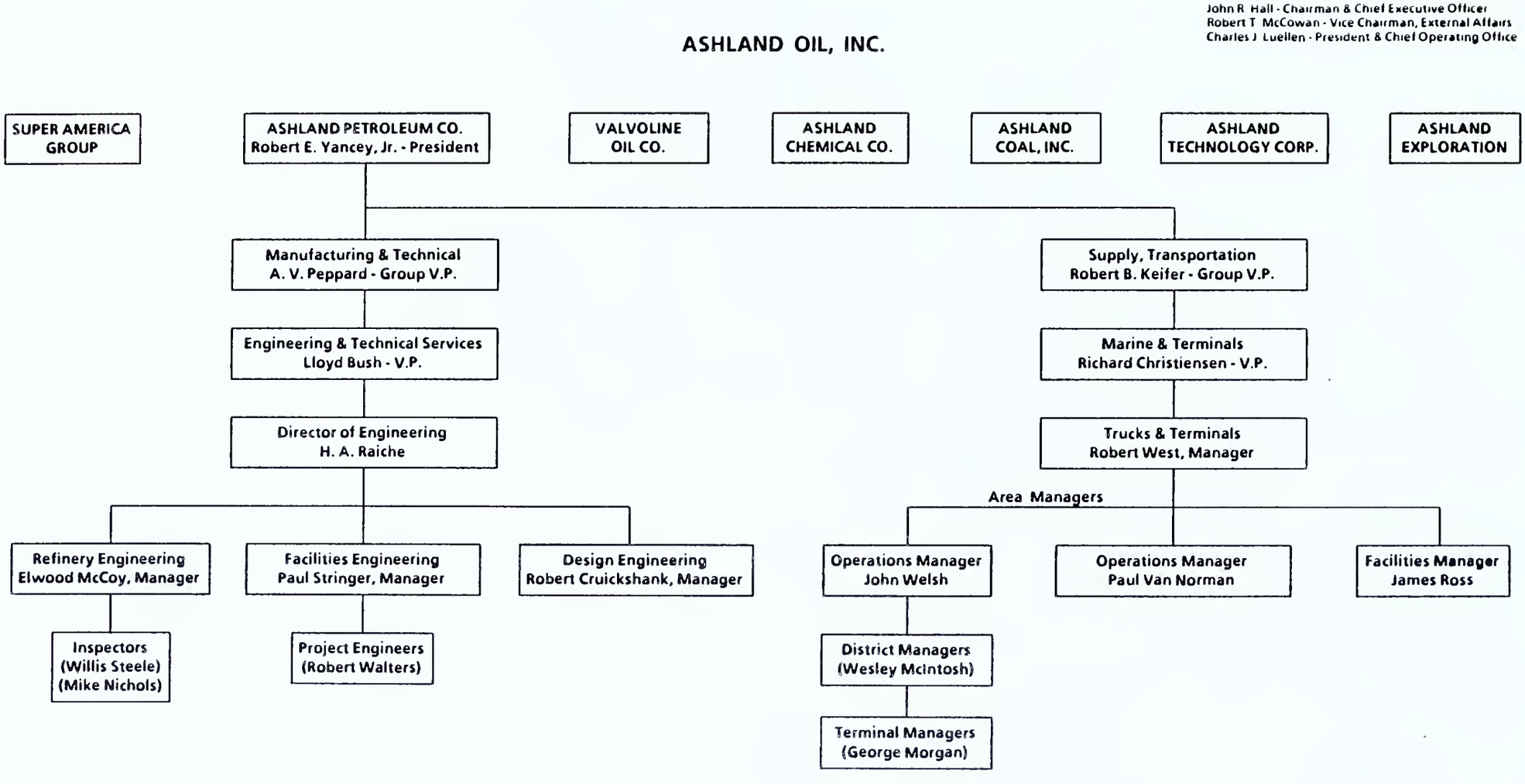


Fig. 1 - Abreviated Ashland Oil, Inc. Organization Chart.

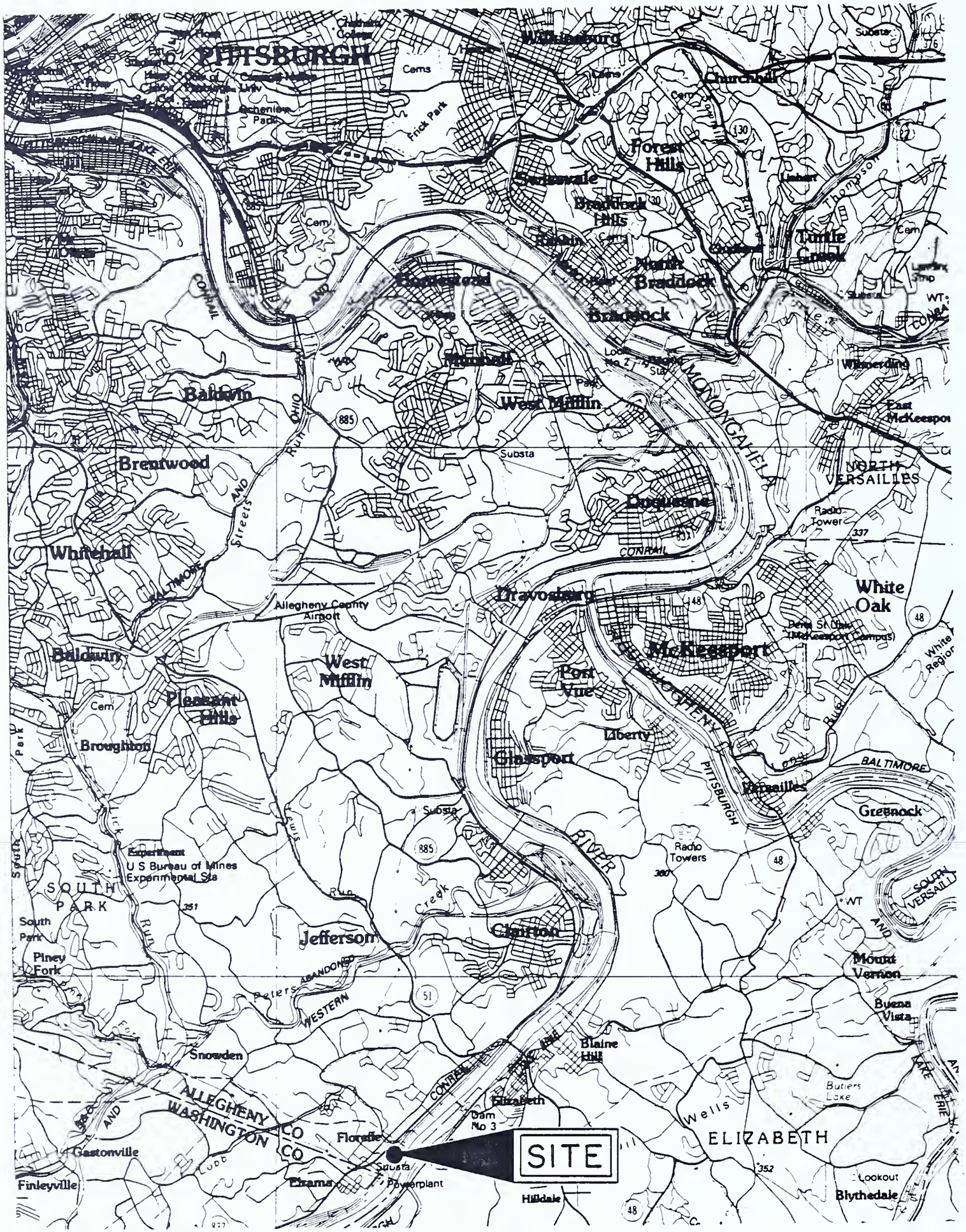
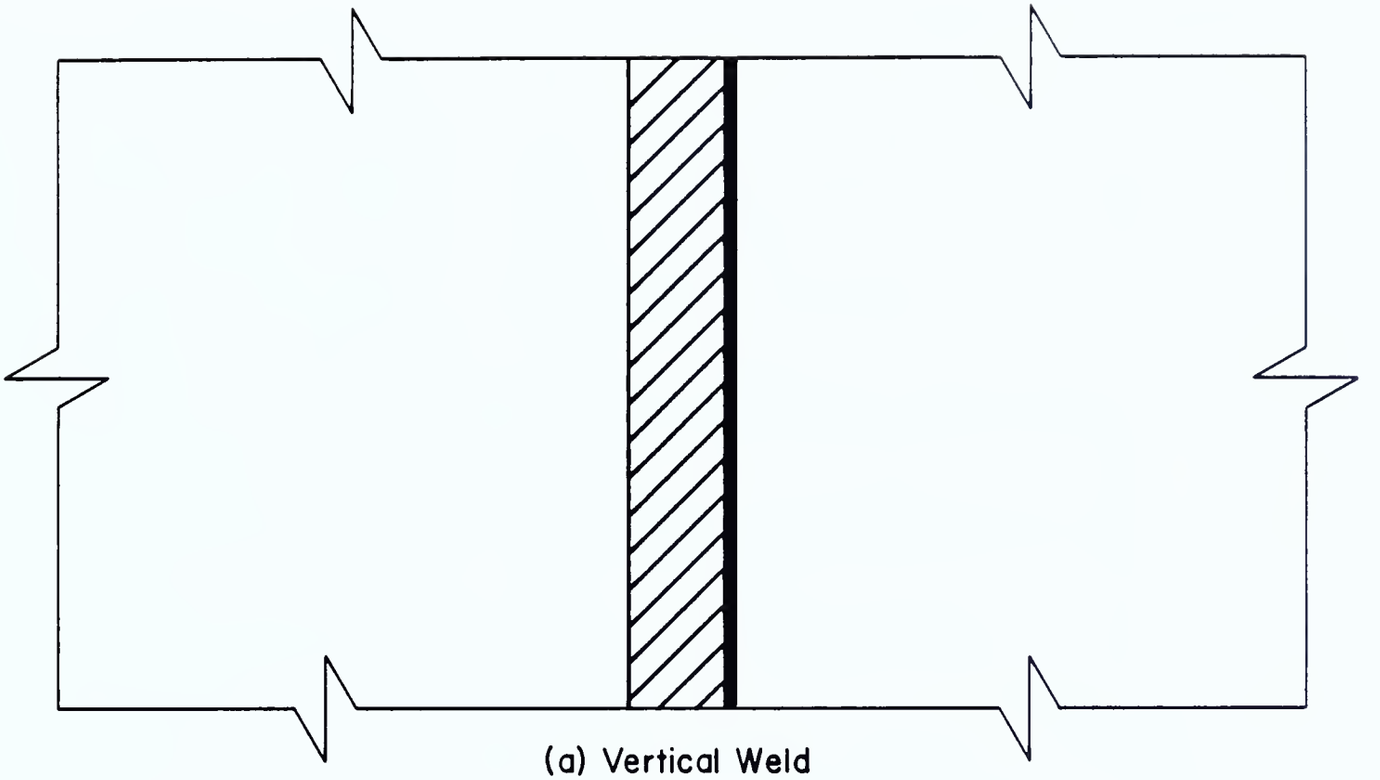
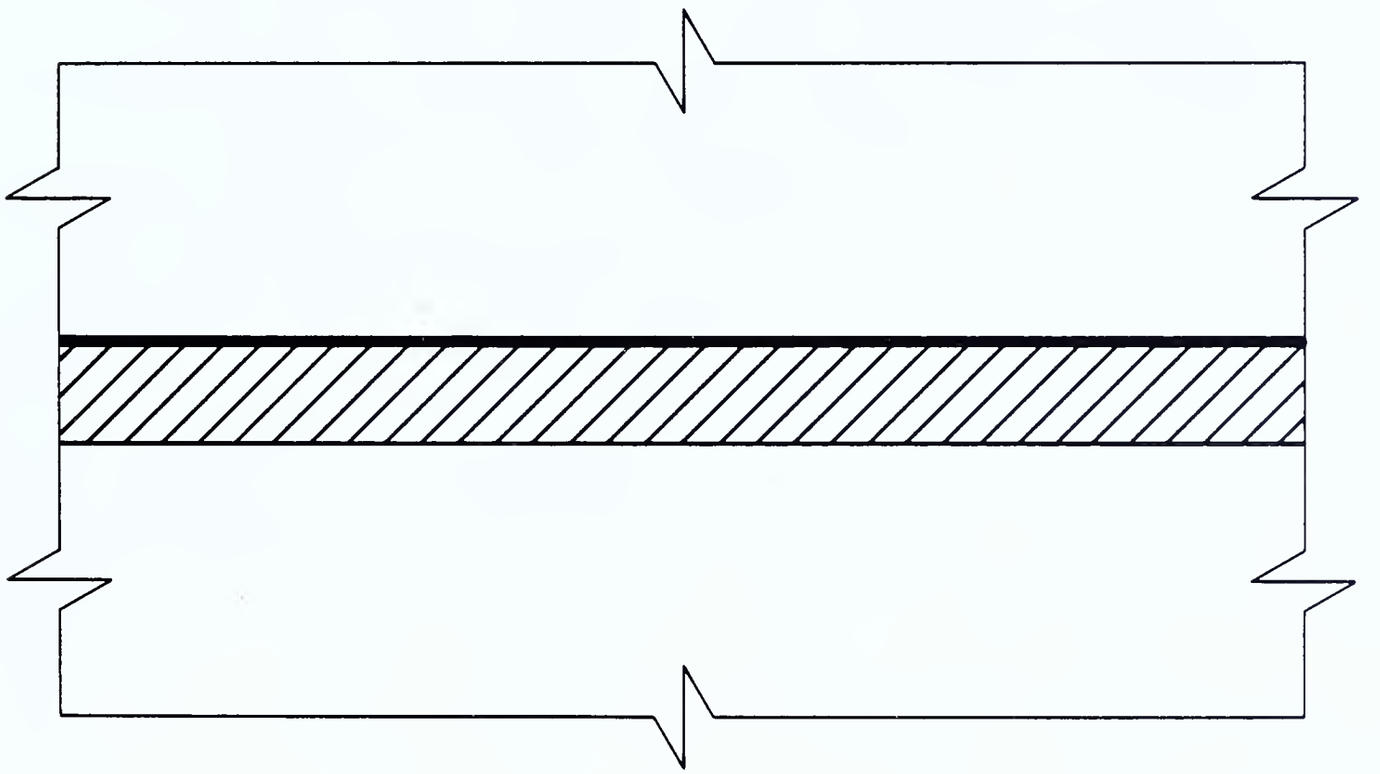


Fig. 2 - Map showing location of the Floreffe terminal.



(a) Vertical Weld



(b) Horizontal Weld

Fig. 3 - Dismantling of WI - 16. The cross hatched areas represent existing welds; the bold solid line represents the location of STC cuts.

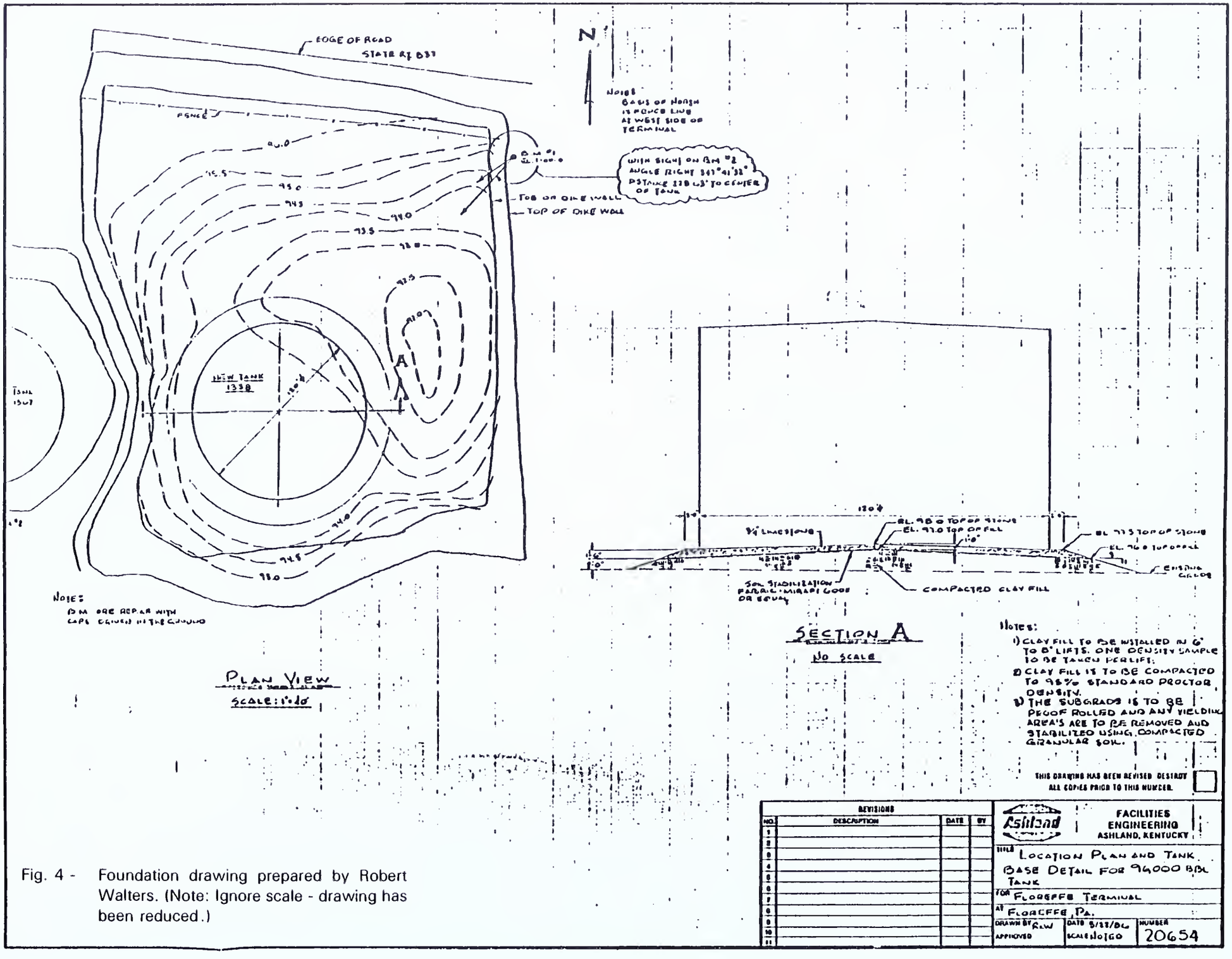

EDGE OF ROAD
STATE RT 837
FENCE
NOTE: BASIS OF NORTH IS FENCE LINE AT WEST SIDE OF TERMINAL
WITH SIGHT ON BM #2 ANGLE RIGHT 341°41'32" DISTANCE 228.43' TO CENTER OF TANK
TOE OF DIKE WALL
TOP OF DIKE WALL
NEW TANK 1338
TANK 1307
NOTE: BM ARE REBAR WITH CAPS DRIVEN IN THE GROUND
PLAN VIEW
SCALE: 1"=10'
SECTION A
NO SCALE
EL. 98.0 TOP OF STONE
EL. 97.0 TOP OF FILL
EL. 93.5 TOP OF STONE
EL. 96.0 TOP OF FILL
EXISTING GRADE
SOIL STABILIZATION FABRIC: MIRAFI 600X OR EQUAL
COMPACTED CLAY FILL
NOTES:
1) CLAY FILL TO BE INSTALLED IN 6" TO 8" LIFTS. ONE DENSITY SAMPLE TO BE TAKEN PER LIFT.
2) CLAY FILL IS TO BE COMPACTED TO 95% STANDARD PROCTOR DENSITY.
3) THE SUBGRADE IS TO BE PROOF ROLLED AND ANY YIELDING AREA'S ARE TO BE REMOVED AND STABILIZED USING COMPACTED GRANULAR SOIL.
THIS DRAWING HAS BEEN REVISED DESTROY ALL COPIES PRIOR TO THIS NUMBER.
REVISIONS
NO. DESCRIPTION DATE BY
Ashland
FACILITIES ENGINEERING
ASHLAND, KENTUCKY
TITLE LOCATION PLAN AND TANK BASE DETAIL FOR 96000 BBL TANK
FOR FLORENCE TERMINAL
AT FLORENCE, PA.
DRAWN BY RLW
APPROVED
DATE 5/23/86
SCALE NOTED
NUMBER 20654

Fig. 4 - Foundation drawing prepared by Robert Walters. (Note: Ignore scale - drawing has been reduced.)

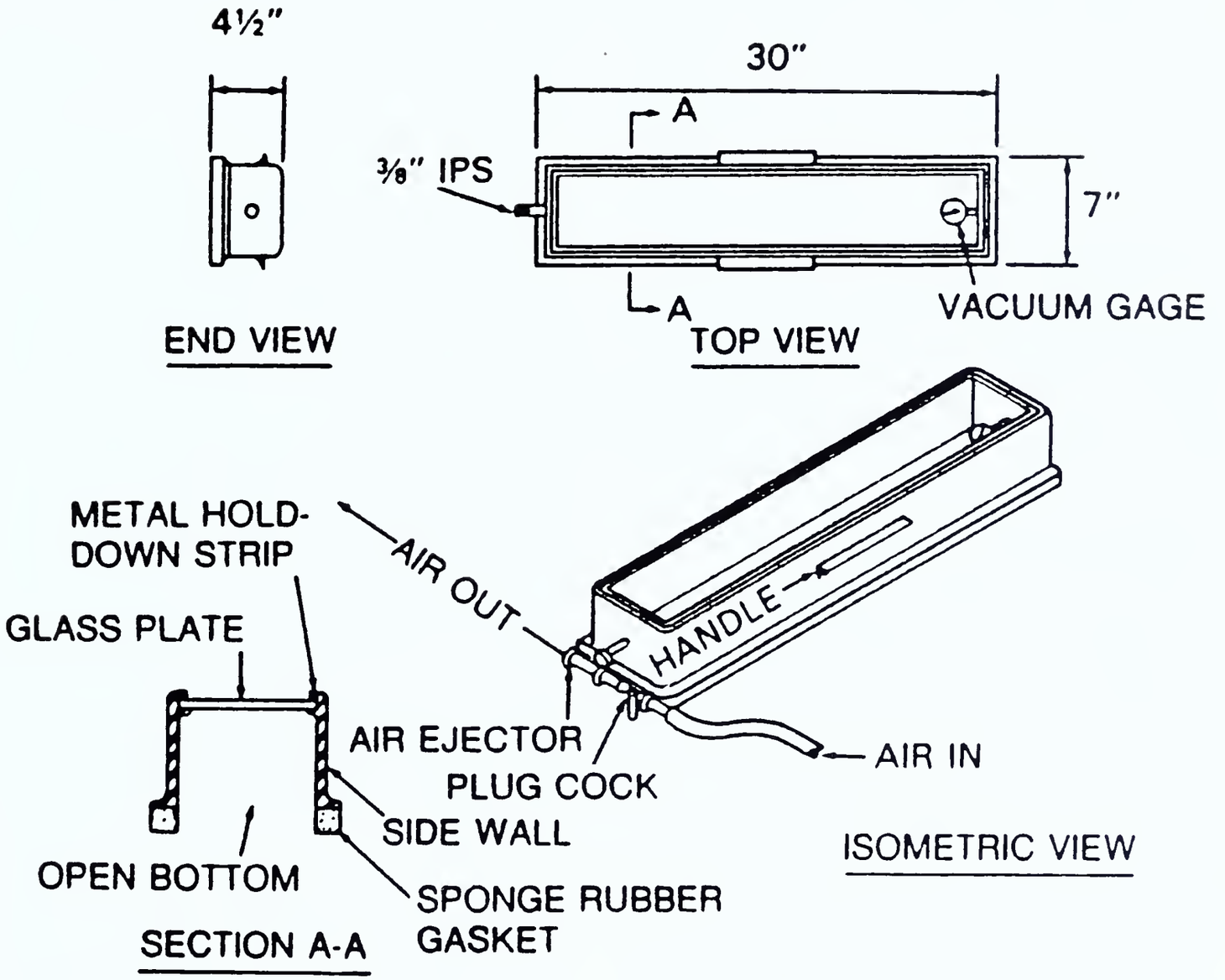


Fig. 5 - Sketch showing a Vacuum Box. (Courtesy American Petroleum Institute.)

III. FAILURE ANALYSIS AND CRITIQUE

A. Introduction

Following the January 2, 1988 collapse, the tank was examined by representatives of Battelle (representing Ashland), NBS, ATLSS, as well as the Task Force itself, and experts retained by plaintiffs in lawsuits against Ashland. Under protocols established at the outset, both sides of the fracture surface have been held by Battelle. One side has been tested and analyzed; the other has been placed in storage for future examination. The other organizations identified pieces of the remainder of the tank which they desired to test or analyze. (Figure 10 is a sketch showing the path of the fracture. Figure 22 is a drawing showing the tank, post-collapse observations and the location of some samples.) All samples were initially sent to Battelle to be cataloged. Subsequently, Battelle forwarded the samples to the parties which had requested them.

Battelle conducted several batteries of tests to determine the chemical composition, mechanical properties, and metallurgical structure of the base material and weld material or materials. NBS duplicated many of the tests done by Battelle.

The Task Force is satisfied with the efforts of Battelle and NBS. These organizations are to be commended not only for the high quality and sophisticated work they performed, but also for the open, professional atmosphere they helped foster. Specific aspects of their work will be addressed below.

B. Engineering and Metallurgical Concepts

1) General

The following discussion has been included to help the reader understand the technical causes of the collapse. It is not intended to be a rigorous scientific or engineering discourse. Concepts have been simplified and minimal liberties taken in the interest of explaining the key concepts and technical results.

All materials have characteristic mechanical properties. The most significant in structural applications are strength and toughness. Strength is a measure of a material's ability to withstand force or force per unit area (stress). Toughness, on the other hand, is a measure of a material's ability to absorb energy. Generally, these properties are inversely related. That is, high strength materials typically have low toughness and vice versa.

A piece of china or ceramic, for example, would be characterized as high-strength, low-toughness material. It cracks easily. On the other hand, a piece of rubber would be considered low strength, high toughness. Though it stretches easily, it is almost impossible to crack. Strength failures typically occur under static conditions. Toughness failures, though often associated with impacts, can also occur in non-impact situations.

Strength is the material property which has historically governed most construction and is the most intuitively obvious design consideration to the non-engineer. Strength-related failure can take two forms — excessive deformation or fracture. In other words, if a material is required to carry a load which is too heavy, it will deform or break. The former corresponds to yield stress loading, and the latter to ultimate stress. These terms are explained below.

When tension force is applied to a material at a slow constant rate, it stretches or deforms until it breaks. A diagram showing stress (force/area) versus strain (deformation/total length) illustrates this relationship and the material's strength characteristics for such slow constant loadings. (A sample stress-strain diagram is shown at Figure 6.) Stress and strain are linearly related until the material reaches the yield point. The associated stress at that point is known as the yield stress. (Point A on Figure 6 is the yield point.) Like a spring, application of a given stress up to the yield stress will cause a predictable deformation. If the

load is removed, the specimen will return to its original length.

The plastic range is that portion of the graph immediately beyond the yield point. (In Figure 6, A-B is the plastic range.) In this region the material continues to deform without an increase in stress, which remains roughly yield stress. The material does not "break", but "deforms" permanently in this region; it will not return to its original length after unloading. After continued loading and elongation at constant stress, stress begins to increase again. This occurs at Point B in Figure 6. After the the maximum or "ultimate" stress is reached the material "breaks." (The material breaks at Point D in Figure 6; "ultimate" stress occurs at Point C.) Ultimate stress is also known as the tensile strength of the material, and the associated failure is called tensile failure. Remember that this scenario is for a slow constant loading; no impact is involved.

Strength is generally measured by a uniaxial tension test. A material specimen of known size and cross-sectional area is placed in a hydraulic testing device and tensile force is applied to it at a constant rate. As the specimen is "pulled," elongation is measured, until failure.

Tensile failure, often called ductile failure, exhibits certain characteristics. The term "ductile" refers to the amount of deformation that occurs before failure. As described above, the material deforms significantly prior to failure during a strength failure. Thus, when loaded slowly to failure the material gives "warning" through elongation; failure does not occur suddenly. In addition, the fracture surface, or location of the break, has a characteristic appearance. The point of fracture itself will appear to be somewhat jagged, with no discernible pattern on its surface. However, the cross-sectional area of the fracture surface and nearby material is reduced, like a piece of salt-water taffy that has been pulled. This phenomenon is known as "necking." In addition, tensile failure is wholly governed by the strength of the material, which is an intrinsic property.

Tensile failure should not be confused with brittle failure, which will be discussed at length below. As will be developed more fully later, brittle failure, by contrast, occurs almost instantaneously and creates its own distinctive fracture surface.

Materials also fail in other ways not germane to the collapse of Tank 1338. These include: shear failure, which is governed by the material's resistance to transverse loading; fatigue failure, which is governed by the system's ability to withstand repeated loading and unloading; and compression failure, which is governed by the structure's ability to resist buckling.

Strength is usually the governing property in structural design. Most structural design codes limit the amount of stress to a fraction of the material's yield strength. A serviceable structure is designed neither to deform significantly nor break under anticipated conditions. The design should provide sufficient reserve strength to avert collapse or significant deformation if unexpected loads are imposed on the structure. This reserve strength is typically provided through design stresses and factors of safety.

Toughness, introduced above, is another material property. It is a measure of a material's ability to absorb energy. In its purest sense it refers to the energy absorbed by a sample of a material, with no notch or flaw, which is slowly loaded to tensile failure under static conditions. (Energy is a force acting over a distance ($E = F \times D$); the distance is the material's elongation and force comes from the stress.) Toughness under these conditions, defined as slow constant loading to tensile failure, can be physically represented on the stress-strain diagram. It is the area under the curve. (Figure 7 shows this; the cross-hatched area represents toughness.)

A toughness related failure, or brittle failure, is a sudden cleavage of the material. Brittle failure occurs when the material tries to absorb a great deal of energy relative to its toughness. Unlike a tensile failure, the material's strength properties are not relevant. Brittle failure typically occur at stresses lower than the material's ultimate stress, and below yield stress. Unlike tensile failure, where the material experiences gradual deformation prior to failure, brittle failure is virtually an instantaneous event. In other words, the material "cracks" rather than "breaking" or "deforming." The mechanism of brittle failure will be discussed in greater detail below. The important point for

now is that it is different than a strength related failure. An image of an everyday item that illustrates this point bears repeating here. Though strong, a piece of china or ceramic cracks easily because it possesses low toughness.

This expression of toughness, however, is not relevant to all brittle fractures that occur under various conditions, such as when impact occurs or when materials contain defects. Indeed, numerous factors affect toughness, and, of course, brittle failure.

Toughness is highly temperature dependent. In fact, strength and toughness are inversely related as a function of temperature. Strength generally increases as temperature decreases; toughness decreases. This relationship can be imagined by thinking about a common item, putty. At room temperature it is easy to pull apart but almost impossible to crack. However, if frozen it becomes hard to pull apart, but easy to crack. Nevertheless, temperature's effect on strength of steel is far less profound than its effect on toughness in the temperature range of interest. For this reason, toughness tests are performed at a variety of temperatures. The temperature at which the material begins to behave brittlely is called the transition temperature. Brittle is the inverse of tough. That is, the transition temperature is the point at which brittle failure becomes more likely than ductile failure. (Figure 8 is a transition temperature graph for a generic material.) The x-axis of a transition temperature graph is temperature; while the y-axis can be used to represent several parameters, energy required to break the sample in a standard test is the most common. The transition temperature occurs at the point where a certain amount of energy, generally 15 ft.-lb., is required to fracture the sample.

Several other parameters affect toughness. Some, like temperature, affect the material itself, while others affect the behavior of a sample. A thin plate is less tough than a thick one. Therefore, toughness measured for a particular sized sample of a given material is not valid for a thicker or thinner sample of the same material. The type of loading, impact or non-impact (*i.e.*, slow gradual loading), significantly affects toughness. A sample subjected to impact loading is much less tough than an identical sample subjected to non-impact loading. The presence of a notch or flaw in material also has a pronounced effect on toughness. As one might expect, the presence of a defect reduces toughness. However, the shape, location, and size of the defect together determine the overall effect. Heating and cooling of material, perhaps experienced in welding or fabrication, can significantly affect toughness. As a rule, heating followed by relatively rapid cooling causes a decrease in toughness. Finally, cold working, or mechanically deforming plates, tends to decrease toughness. This effect, fortunately, is rarely a significant one and is typically discounted. The last two, as well as temperature, intrinsically affect the material's toughness; the others relate to brittle behavior but not the material *per se*.

In summary, the following factors affect a material's behavior: type of loading (impact, non-impact), geometry, temperature, past heating and cooling, and presence of a defect. Based on the sheer number of factors, it is exceedingly difficult to determine a material's toughness under all imaginable circumstances. Complicating matters further, some effects, heating and and cooling for example, are not uniform through the full material. Furthermore, many of these factors are not intrinsic to the material; in particular, type of loading, geometry, and defect.

Engineers have dealt with this problem by devising measuring techniques which address a few variables by testing standard sized samples. The result is a relative, if not universally accurate, value which is used for comparison between materials. The most common measure of toughness is known as "notch-toughness." Notch-toughness is the amount of energy required to break a specimen of specified size with a specified defect or "notch." Typically, an impact load is applied.

The most commonly used notch toughness test is the Charpy V-notch test. A specimen of standard size with a standard notch, supported only at its ends, is placed in the testing apparatus. A free falling hammer hits and breaks the specimen. The energy required to break the specimen is measured; this value is the Charpy V-notch toughness. Obviously, the higher the notch toughness the more energy required to break it.

As stated above, notch-toughness is not a universally quantifiable, intrinsic material prop-

erty. The characteristics of the material's particular application affect it. It provides only a relative measure; the actual test values themselves are only relevant for the standardized notched specimens prepared for the test. Still, the Charpy test is easy, cheap and well established. Though engineers have debated the value of conclusions drawn from Charpy tests, Charpy V-notch toughness values are often used in material specifications. API-650 , for example, relies on this technique. Transition temperature has been historically defined at a Charpy V-notch toughness of 15 ft-lb. As discussed earlier, the transition temperature, the defined point at which a material is said to act brittlely, obtained from Charpy V-notch tests using impact loading would be higher than if the same test was performed under non-impact loading. Fortunately, this provides a margin of safety.

Other toughness testing methods have been developed, but the Charpy V-notch test is the most common toughness measure. However, in recent years notch-toughness tests have been increasingly supplemented and sometimes superseded by a new measure of toughness determined through different tests. This new expression of toughness is generally known as the fracture toughness. A fracture toughness, unlike notch toughness, is a true material property and is independent of such things as thickness, specimen size and notch parameters. Of course, intrinsic factors like temperature, as well as type of loading, do affect the value. The relevant tests tend to be very expensive and the requirements to obtain valid results very rigorous. Different tests for impact and non-impact loadings are required. Nevertheless, this development has provided a large step forward in the understanding of brittle fractures. Fracture toughness is used in the relatively new and complex discipline of fracture mechanics. An engineer using fracture mechanics can predict the brittle behavior of a structure with a reasonable degree of certainty. A more detailed discussion of fracture mechanics is not feasible in this report.

2) Brittle failure

Brittle failure, as mentioned in the prior section, is a toughness related mode of failure, and occurs when material is loaded under certain critical conditions. The failure mechanism is far more complex than a strength failure because so many factors affect toughness. These factors are: 1) stress, 2) temperature, 3) geometry, 4) defect in the material, 5) type of loading (impact, non-impact), and 6) past effects of heating. These factors affect each material and each sample differently.

Brittle fracture can be logically divided into two types based on loading: impact and non-impact. Impact loading involves a high rate of strain or deformation. Brittle fractures which result from impacts are intuitively logical. An impact loading obviously imparts a great deal of energy to the material. If the energy is too great to be absorbed it cracks, like smashing a tea cup with a hammer. It is easy to understand that brittle fractures can occur under these conditions.

Non-impact brittle failures are, nevertheless, a real, if counter-intuitive, phenomenon. They are not unlike a tea cup full of coffee suddenly failing. Non-impact loading is load applied at a very low rate of strain or deformation, essentially a static situation. Since toughness is a measure of energy absorbed, the logical problem is identifying a source of energy. Unlike an impact loading situation the source of energy is not obvious. Energy is present, though perhaps not evident to the casual observer. For example, in the case of Tank 1338 energy is stored in the tank itself, a result of the product which it contains. The amount of energy is directly related to the amount of product stored. The devastation at the Floreffe terminal when Tank 1338 collapsed graphically demonstrates the incredible amount of energy that was stored in the tank. The remainder of this section will focus on the particular factors which affect non-impact brittle fractures in a structure like an oil storage tank.

Once the type of loading and structure of interest are known, many of the factors listed above can be eliminated and other remaining variables can be grouped together. Of course, the type of loading, non-impact, is assumed. The size of the plates in the tank will not change, and can be eliminated as a variable. Since both affect the material *per se,* the effect of prior heating and temperature can be grouped together and associated with material toughness.

Brittle failure requires three factors: 1) stress, 2) a low toughness material, and 3) a notch or flaw in the material. (Ref. 1, 2, 3, 4) The latter is simply a point where the cross-sectional area is reduced; stresses are elevated or "concentrated" at this point. If any of the three factors are missing or not present in a sufficient magnitude, brittle fracture will not occur. The three factors are also balanced against each other. (Figure 9 illustrates this relationship.) For example, a notch too small to cause brittle failure at one temperature might cause brittle failure in the same material at a lower temperature, when toughness is reduced. Similarly, increased stress at the higher temperature may be sufficient to cause brittle failure.

Like tensile failure, a brittle fracture has it own identifying features or "fingerprints." The fracture surface is characterized by triangle shaped, herringbone marks called "chevron marks." These marks "point" to the initiating location, *i.e.*, the location where the fracture began. This is almost always a notch or flaw. Unlike strength failure, the cross-sectional area at the fracture surface is not reduced. Finally, brittle fractures are practically instantaneous events, which happen without notice. There is no deformation prior to failure, as in a strength failure. (Photo 11 is a portion of the fracture surface of Tank 1338 showing chevron marks.)

Brittle failure in steel plates was not well understood for a long time because the failure could not be reproduced in the laboratory. When a steel plate, taken from the structure that had failed in a brittle manner, was subjected to conventional tension tests, the material showed a high degree of ductility and met all necessary strength requirements. Needless to say, this was quite baffling to engineers who studied the phenomenon of brittle failure. The problem of not understanding brittle fracture, when static tension tests showed perfectly good results, was perhaps first reported in 1879 in a discussion of the merits of using steel plates for ship-building over the then conventionally used wrought iron.

The Bessemer steel making process was introduced in 1856 and the open hearth process in 1861. Prior to these advances, steel was scarce and very expensive to obtain. Brittle failures were unknown in structures of wrought iron because its high slag inclusion content was able to arrest crack propagation by blunting an advancing crack. In the years from 1860 to 1890, wrought iron was gradually replaced by steel as a structural material. Eventually, the cost, availability, and generally superior properties of steel made it a suitable candidate for engineering structures and wrought iron was almost completely replaced. As more structures began to be constructed out of steel, troubles due to brittle failure began to appear.

Some of the earliest failures in engineering steel components were attributed to "bad" materials, corrosion, excessive loading (overstress), or poor workmanship during fabrication. Moreover, it was found that structures often failed on windy days, when subject to sudden impact, or when the ambient temperature had dropped significantly just before the failure had occurred. The last point had engineers baffled; they could not understand why a perfectly "ductile" material would fail in cold weather.

Such sudden failures were not understood until after the Second World War. Brittle failures of welded Liberty ships and T-2 tankers during the Second World War intensified interest in brittle fractures. Several of these vessels broke at sea and at dockside. These disasters have led to thorough investigations and have helped in our understanding of the brittle fracture problem.

There have been many failures of storage tanks over the years. Some have had little influence on the general public. Others have led to loss of life, injuries and litigation, and careful investigations have followed. However, such cases are difficult to obtain from the open literature. Often, the records of structural failures have been closed to public review and have not been reported in the press or technical literature. The Task Force briefly reviewed failures reported in public literature. That review has uncovered reports of no fewer than 36 historic brittle failures in similar structures. This topic is addressed somewhat more extensively in the "Conclusions and Recommendations" section of this report.

Considering the total number of engineering structures in use throughout the world today, not simply storage tanks, the number of brittle failures of these structures is small indeed. Tacitly, designers have historically relied upon factors of

safety applied to the maximum calculated stress level, and design stresses based on some percentage of the yield or tensile strength, to prevent brittle failures. Nevertheless, brittle failures of large engineering structures become increasingly common with increased complexity of design and the use of high-strength, thick welded plates in lieu of lower-strength thin, riveted material. Moreover, when minimization of costs dictates construction methods and more precise computer-calculated designs increase load capacities or decrease actual factors of safety, the historical approach is essentially undermined. The designer, then, must be aware of the available techniques to avoid brittle failure.

Furthermore, the historical approach, by itself, may be outdated because large complex structures are not fabricated without some internal flaws, defects or discontinuities. These defects may have been introduced during manufacture or fabrication processes such as rolling, machining, punching, or welding. The size of such defects may range from very small imperfections which escape detection during inspection procedures, to gross macroscopic discontinuities several inches long.

A defect or discontinuity was responsible for almost every reported brittle fracture of engineering structures. Such defects have originated from torch-cut edges, gouges, corrosion pits, weld repairs, and severe stress concentrators. The importance of defects in an engineering structure cannot, therefore, be understated. While inspection techniques have improved, a defect-free structure cannot be assumed. It is prudent to design a structure and specify materials based upon the maximum size of a defect that the testing procedure will miss during inspection, rather than the minimum size defect that the technique is able to detect. In recent years, structural failures and the need for safety and increased reliability have led to the development of various design criteria for such engineering structures as pressure vessels, airplanes, bridges, pipelines, drilling platforms and space shuttles.

Our understanding of the brittle fracture problem has been strongly influenced by the advent of fracture mechanics. The field is now so well advanced that it provides effective methods for fracture prevention. Almost all specifications for modern fracture control rely on the concepts of fracture mechanics.

Fracture mechanics has successfully demonstrated that because materials, design, fabrication and loading conditions are interrelated, the use of materials with improved notch-toughness does not necessarily eliminate the brittle fracture problem. It predicts the relationship between the three major factors that essentially control the conditions for fracture in an engineering structure: material toughness, design stress levels, and flaw size. Based on these parameters, it is possible to determine material toughness requirements, and thereby select suitable metals and alloys, determine the maximum allowable defect size as governed by inspection procedures, and set limits on the stress levels that may be tolerated without brittle fracture during service. Therefore, the designer is able to quantitatively balance the three factors—toughness, stress, flaw size—and determine the relative importance of each during design rather than after failure. A well-defined fracture control plan then becomes one of the most important parameters in deciding the service life of an engineering structure. A knowledge of service conditions to which the structure will be subjected (*e.g.*, temperature, loads, load rate), material toughness, and the consequences of structural failure are important in ensuring a failure-free life.

Our understanding of fracture mechanics has led designers today to subscribe to a "leak-before-break" philosophy. The maximum allowable flaw size is chosen so that a flaw grows and the vessel leaks rather than breaking (*i.e.* brittle failure). In this fashion, the structure provides its own early warning indicator of possible integrity problems by leaking, which presumably triggers corrective action.

C. Construction Standards

At least three organizations have promulgated standards applicable to the design, manufacture and construction of above ground storage tanks: The American Petroleum Institute (API), the American Water Works Association (AWWA), and Underwriters Laboratory (UL). Of these three the API standards are the most widely

utilized in the petroleum industry. The AWWA code is only applicable to water tanks. The UL aboveground tank code (UL-142) is expressly limited to tanks made of new steel with a capacity of 50,000 gallons or less. It is also much less detailed than API-650. The Task Force uncovered no companies that utilized UL-142.

API is a petroleum industry trade association established in 1919. Its functions include establishing technical standards for the industry, gathering and processing data on the industry, and lobbying and otherwise supporting the development and interests of the petroleum industry. Standards are written by committees dedicated to particular subject areas. The individuals who sit on these committees are volunteers, generally employees of member companies. All of API's standards are voluntary, but are generally recognized in the industry. In addition, many API standards have been adopted by the American National Standards Institute (ANSI) as American National Standards, lending additional credibility to them. Those standards adopted by ANSI are adopted as "consensus" standards. To achieve this designation, API canvasses the industry for comments to a proposed standard. It addresses all comments received, if possible. This procedure is designed to assure that the standard promulgated represents the consensus of the industry on that subject.

API has promulgated many codes and standards applicable to above ground storage tanks. These include:

API-12B — Bolted Tanks For Storage of Production Liquids

API-12D — Field Welded Tanks For Storage of Production Liquids

API-12F — Shop Welded Tanks For Storage of Production Liquids

API-12H — New Bottoms for Old Tanks

API-12P — Fiberglass Tanks For Storage Of Production Liquids

API-620 — Large Welded Low Pressure Storage Tanks

API-650 — Large Welded Storage Tanks (Atmospheric)

In addition other API standards cover such topics as Venting Storage Tanks (API-2000), Fire Protection and Fire Fighting (API-2001, API-2021), Protection Against Electrical Ignition (API-2003), Cleaning Storage Tanks (API-2015), Evaporation Loss (API-2517), Measurement and Calibration (API-2550, API-2555), and Inspection Of Storage Tanks (Guide For Inspection Of Refinery Equipment, Chapter XIII). Some, but not all of these, have been accepted as American National Standards.

API-650 is applicable to the design, fabrication, and construction of large non-pressurized steel storage tanks typically found at refineries and petroleum storage terminals. The scope of API-650 is defined in Section 1.1.1, which states, in relevant part: "[t]his standard covers material, design, erection and testing requirements for vertical cylindrical above ground closed and open-top, welded steel storage tanks in various sizes and capacities for internal pressures approximating atmospheric pressures." Unlike UL-142, API-650 does not contain an express size limitation, and is not expressly limited to tanks built of new materials.

API promulgated its first tank standard, API-12C, in 1936. In 1961 the first edition of API-650 was published. Since then it has been reissued several times; the current edition, the seventh, was first issued in November, 1980, and was revised in 1984. A draft of the eighth edition is currently being circulated for comments. All API standards are revised at least every five years. The standards' requirements have changed significantly over the years. Table 1 is a chart which illustrates this point by comparing certain provisions of the last edition of API-12C, published in 1958, and the current version of API-650.

API answers questions about the application and interpretation of its standards. Annually, it publishes those questions and answers and makes the document called "Interpretations - Technical Publications" available to the public. API stated to the Task Force categorically that the provisions of API-650 can be used for the reconstruction of tanks. API reasons that the source of the material used to construct a tank is not relevant. The important point is that a "tank" is being built. There is a significant split in the industry on this issue. Some companies believe that it does, others do not, but believe that it should be followed as a matter of good practice. The standard

does not expressly address rebuilt tankage. Similarly, there is also a division of opinion among Ashland employees on whether API-650 applies to rebuilt tanks.

Finally, though API-650 was written for the petroleum industry, API is aware that the standard is often used for such other applications as chemical and water storage. The Center for Chemical Process Safety of the American Institute of Chemical Engineers has recently published "Guidelines for Safe Handling of High Toxic Hazard Materials." The guideline recommends following API standards when designing chemical storage tanks.

There are also other requirements applicable to aboveground storage tanks. Portions of the National Fire Protection Association's Flammable and Combustible Liquids Code (NFPA-30) are relevant to above ground storage tanks. The primary focus of NFPA-30 is reducing the risk of fire and explosion to the public from storage of flammable and combustible liquids. NFPA-30 incorporates API-650 expressly in the area of construction standards.

Tanks owned and operated by pipeline companies for the transportation of petroleum products are regulated by the United States Department of Transportation. The applicable regulations are set forth at 49 C.F.R. 195. Therefore, storage tanks covered by these regulations were not investigated and will not be addressed in this report.

Table 1
Contrast Between API 12C-1958 and API-650 Codes for Welded Oil Storage Tanks

Welding Requirements

API 12C

Shielded metal-arc, submerged arc processes.

No specification of welding rods.

API 650

Shielded metal-arc, gas metal-arc, flux-cored arc, submerged arc, electroslag processes.

Use low hydrogen welding rods for thicknesses greater than 0.5", involving manual welding.

Weld Procedure and Welder Qualification

API 12C

Manufacturer must perform a series of tests to demonstrate their ability to make welds. The types of welds and geometries are listed in the specification.

API 650

Manufacturer must perform series of tests as per ASME Boiler and Pressure Vessel Code.

Material Requirements

API 12C

ASTM A7 (open hearth or electric furnace only)

A283 C
A283 D no thicker than 0.75"
A131 A, B, C
A201 A, B
A284 B
A373

No toughness requirement.

API 650

ASTM A283 C maximum thickness (t) 1.0"
A285 C max t 1.0"
A131 A max t 0.5"
A131 B max t 1.0"
A131 C max t 1.5"
A131 EH36 max t 1.75"
A36 max t 1.5"
A442 55,60 max t 1.5"
A573 58, 65, 70 max t 1.5"
A516 55, 60, 65, 70 max t 1.5"
A662 B, C max t 1.5"
A537 class 1, 2 max t 1.75"
A633 C, D max t 1.75"
A678 A max t 1.5"
A678 B max t 1.75"
A737 B max t 1.5"

API 650

ASTM A283 C maximum thickness (t) 1.0" Cont'd

Toughness Criteria: Impact strength must meet set values depending on the thickness and expected temperature of the environment.

Inspection

API 12C

Sectioning - (For Vertical Welds) - 1 section in 1st 10', then one section every 100'. For Horizontal welds, 1 section in the 1st 10', then one section every 200'. Samples are to be cut so as to provide two cross section views, plus material from the surrounding plates.

Radiography - as an alternative to sectioning, using the same location criteria as sectioning.

Visual Inspection - in the event that a weld appears faulty, radiography must be used to determine if weld is to be accepted or rejected.

Hydrotesting

Vacuum Testing

API 650

Radiography - more rigorous than API-12C. Number of radiographs depends on plate thickness.

Magnetic Particle - as per ASME Boiler and Pressure Vessel Code.

Liquid Penetrant - as per ASME Boiler and Pressure Vessel Code.

Ultrasonic Inspection - as per ASME Boiler and Pressure Vessel Code.

Hydrotesting

Vacuum Testing

Design

API 12C

max stress 21,000 ksi before any factor of efficiency.

min thickness = 0.0001456D(H-1)S

D=nominal diameter of tank, ft.

H=max liquid level above the bottom of the course in question.

S=Specific gravity of material stored, if material has specific gravity less than 1.0, a value of 1.0 is used for S.

API 650

max design stress varies with the actual material being used; it is 2/3 of the YS. Actual value given in a table in the standard.

$$\text{min thickness} = \frac{2.6D(H-1)G}{S_d} + \text{C.A.}$$

G=specific gravity of stored material

S_d=design stress

C.A.=Corrosion Allowance

D,H are the same as in API 12C

Shell Openings

API 650

Thermal Stress relief of 1100°F.-1200°F., for 1 hour per inch of thickness, on certain openings.

Welds must be inspected.

D. Causes of the Collapse of Tank 1338

1) Summary

Battelle and NBS addressed the cause of the collapse of Tank 1338. Their efforts considered several possible causes and concluded that the collapse was caused by a brittle failure, which initiated at a flaw in the shell approximately seven feet ten inches (7'-10") from the base of the tank under static loading supplied by an almost full load of product, and toughness reduced by low temperatures attributable to changes in the tank's service. No preceding event or impact was required to cause the collapse. (Photo 12 shows the collapsed tank shell and approximate flaw location; Photo 13 is a close-up view.) The Task Force concurs with this conclusion, but supplemented the efforts of Battelle and NBS with additional testing and analysis, and a detailed geotechnical investigation. Other possible failure modes were also considered.

2) Physical evidence

There is no physical evidence that the primary fracture of Tank 1338 was any thing but a brittle fracture. (Photos 14, 15 and 16 are photographs of the fracture surface and flaw.) As discussed before, herringbone patterns known as chevron marks, which indicate brittle fracture, are present here. Chevron marks "point" to the origin of the failure and in this case the chevron marks, both above and below the flaw, "point" to a flaw located approximately seven feet ten inches from the bottom of the tank. Thus, it is the apparent initiation point of the critical brittle fracture. The flaw itself will be discussed in greater depth later.

Other brittle fracture characteristics manifested themselves in the collapse of Tank 1338. Brittle fractures are virtually instantaneous, occur without warning, and after initiation run across the full length of the plate or member without arresting. Witnesses report that the failure was very abrupt. There was clearly no warning or indication of danger. An Ashland employee was on top of the tank only minutes before the collapse; he observed nothing odd or dangerous. The fracture clearly ran through the whole height of the shell. The great displacement of the tank, some 120 feet, and destructive effect of the product released also suggest an abrupt fracture which suddenly released a great deal of energy. The fracture surface showed no signs of cross-sectional reduction which would accompany a strength related failure. Finally, the steel was manufactured some 45-50 years ago. Such steels typically possess low notch-toughness properties. It is interesting to note that the fracture crossed welds but did not follow them. Apparently, the weld metal was tougher than base metal. Material properties will be discussed further in another section.

Due to the great amount of energy released brittle fractures are usually accompanied by a sharp report—like a gunshot. However, with the exception of the indirect account described earlier, there is no evidence of such a sound here. Nevertheless, the Task Force believes that this apparent anomaly can be explained. It is likely that the diesel fuel in the tank muffled or "damped" the sound. The absence of evidence of this sound, therefore, is not critical.

In summary, the physical evidence which is consistent with the theory that the collapse of Tank 1338 was a brittle fracture are 1) chevron marks which are characteristic of a brittle fracture 2) a flaw in the material 3) steel produced in an era when most steels had low toughness properties 4) practically instantaneous fracture.

3) Testing and analysis

As discussed above, the Task Force worked with the other interested organizations and has reviewed their testing procedures and results, analyses, and conclusions. The Task Force is satisfied with these efforts, and adopts the analyses, results, and conclusions of Battelle and NBS. The reader should refer to the reports of Battelle and NBS for a detailed technical discussion. Those reports conclude that the brittle fracture initiated solely due to static stresses.

a) technical data

In an ideal world, physical observations could all be substantiated by engineering calculations and reproduced in the laboratory. Unfortunately, this is not always possible; the collapse of Tank 1338 is such a case.

Despite the strong physical evidence supporting brittle failure, neither Battelle nor NBS were able to definitively prove through engineering calculations and testing that brittle fracture was the primary cause of the collapse rather than a secondary one. NBS performed a computer analysis of the tank which calculated that the applied static stress from the product would not exceed 13.1 ksi. Therefore, the yield stress, or about 33.0 ksi, has been assumed. The latter stress level is derived by combining applied stresses and residual stresses. Residual stresses are created in the tank by welding and fabrication. Though residual stresses could not be accurately measured since the tank had collapsed and the joint itself fractured, Battelle and NBS have assumed that these residual stresses combined with applied stresses would produce a total yield stress. The Task Force concurs with Battelle and NBS that this assumption is justified. The reader should refer to their reports for a more detailed discussion of the technical basis for the assumption.

In addition, the calculated fracture toughness, K_C, for the base metal was between 45 and 50 ksi $(in)^{1/2}$. Using fracture mechanics techniques, Battelle and NBS determined that this is less than the value needed to predict a brittle fracture for this flaw at yield stress. The reader should refer to the reports of Battelle and NBS for an in-depth discussion of the problems and quirks encountered in the fracture toughness tests and a full explanation of the calculations performed.

The flaw was heated and embritttled, that is made less tough than the surrounding material, years ago when it was created by a cutting torch. The flaw's origin and location will be discussed more extensively later. As discussed above, toughness decreases when a material has been exposed to elevated temperatures and rapidly cooled. It is not possible to quantify the extent of toughness decrease suffered here. Both Battelle and NBS conducted experiments in which they tried to duplicate the embrittlement at the flaw. Samples from the tank were heated, cooled and tested. These experiments showed that the toughness decreased, but yielded no quantifiable results. The reader should refer to the reports of Battelle and NBS for a thorough discussion of these procedures and results. Nevertheless, the Task Force has reviewed the testing and analysis of Battelle and NBS on this issue and agrees with their conclusion that the notch toughness of the heat affected zone near the flaw was lower than the surrounding base metal, and low enough to allow the brittle fracture to initiate with only static stresses. No preceding event or failure was required.

The fracture toughness tests conducted by NBS and Battelle did not meet the rigorous standards for such tests established by ASTM. This shortcoming is due to the material rather than the efforts of these organizations. Consequently the so-called fracture toughness values derived are at best approximations. The reader should, again, refer to the Battelle and NBS reports for a detailed discussion of this technical matter.

b) ductile fractographic analysis

The Task Force finds the failure mechanism identified by Battelle and NBS to be consistent with the evidence. Nevertheless, in an attempt to assure itself and the public that a brittle failure was the primary cause of the collapse the Task Force, through ATLSS, performed additional testing, beyond that conducted by Battelle or NBS.

During the collapse, the shell ripped away from the floor of the tank, breaking the floor adjacent to the fillet weld which joined the shell and floor. The floor remained virtually intact and stationary; the shell moved more than 100 feet and was badly damaged. The relatively clean separation of shell from the floor and the location of the final resting places of these various components after the collapse gave rise to speculation that the tank failure originated in a primary sundering of the shell from the base, with the vertical tear across the flaw actually being a secondary failure mode. A 1972 collapse, which originated in a defect in the weld between the shell and tank floor, bears a striking identity to the appearance of Tank 1338 after its collapse. (Figure 11 shows the orientation of tank debris from the 1972 tank failure.) Other cases of tank collapses originating in the floor have also been documented. (Ref. 1) Given the record of these prior collapses and the inability to reproduce the collapse on paper or in the laboratory, the Task Force thought it prudent to attempt to confirm the cause of the collapse by other analyses.

Accordingly, the Task Force chose to utilize a method called Ductile Fractographic Analysis. It involves Scanning Electron Microscope (SEM) examination of both sides of the floor fracture at the edge of the fillet weld to determine the type and direction of the fracture. Small dimples, not visible to the naked eye, indicate the direction of tearing and mode of failure.

Prior to the Ductile Fractographic Analysis, it was believed that if a brittle fracture at the main fracture was the primary cause of the collapse, the shell would have pulled away in both directions circumferentially from the floor shell starting at the intersection of the vertical rupture and the floor. (This is illustrated in Figure 13.) This would effectively eliminate any other prior failure in the floor plate. If brittle fracture at the main break was the primary cause of the collapse, however, the floor plate could have fractured in any number of ways other than that one. Therefore,

the Ductile Fractographic Analysis could only disprove the possibility of other failure modes.

Several samples were cut from both sides of the fracture for this purpose. The specimens were analyzed on Lehigh University's SEM, an extremely powerful device designed to closely and precisely examine metal surfaces.

This analysis, however, did not show that the the shell tore away from the floor circumferentially in both directions from the main fracture. Instead, the direction of the fracture at locations 1 and 2, on each side of the main break, is roughly perpendicular to the tank's perimeter. (These results are shown graphically in Figure 13.) No detailed technical analysis of the procedure and results has been included with this report. These results are not inconsistent with the conclusion that the main fracture caused the collapse of Tank 1338, because floor failure following brittle fracture of the shell could have taken many forms, including this one. However, neither do the results definitively refute the possible initiation or the fracture elsewhere. In a word, the Ductile Fractographic Analysis was inconclusive. Due to these results, other samples were not analyzed.

c) flaw

Battelle reported that the initiating flaw has existed in the steel since fabrication, over 40 years ago. The flaw abuts a boundary of "old" weld metal and base metal that was once the top edge of the plate. Battelle's fractographic and metallurgical analyses show that the "old" and "new" horizontal welds are partially separated by base metal in the area of the flaw. It also determined that Skinner Tank Company did not cut across the "old" weld. (Figure 14 is an idealized sketch showing the location of the flaw with respect to the welds and base metal.) Apparently Skinner Tank Company departed from its "procedure" and cut through base metal rather than at the upper edge of the horizontal weld. Thus, Battelle postulates, the flaw could not have been caused during the disassembly and re-erection process, but before initial welding, perhaps during plate fabrication or manufacture. As discussed earlier, the time and place of the tank's fabrication cannot be confirmed. According to Battelle, the flaw existed without incident in the tank in its prior use at Whiskey Island. Thus, it was not unlike a bomb which, if not detected by appropriate inspection procedures and then defused, remained quite "live" waiting for creation of the conditions necessary to detonate it. Filling the tank to permissible capacity in cold weather, which may not have been previously encountered during service with heated No. 6 oil at Whiskey Island, apparently were the conditions needed to trigger the "bomb" to explode.

After reviewing Battelle's fractography, metallography, and other data, the Task Force agrees with its explanation of the flaw's origin and "mapping" of the surrounding portion of the fracture surface. The flaw was, indeed, "insulated" from the reassembly effort by layers of base metal and "old" weld metal. Thus, the flaw could not have been created during the relocation of Tank 1338. There is, however, no creditable way to determine the precise origin of the flaw. Battelle has determined, due to carborization of the flaw's surface, that it was caused by an oxy-acetylene torch. The Task Force also accepts this conclusion. Since these torches are very common and the steel's background is essentially unknown, any attempt to tie the flaw's creation to the manufacturer, fabricator, or original erector of the plates would be nothing more than pure conjecture.

Battelle, however, has also determined that the flaw is not located within the heat-affected zone of the "new" welds, but was heat affected during its own creation by a torch. Again, after examining Battelle's metallography and fractography the Task Force agrees with this assessment. A heat affected zone can be seen around the edge of the flaw, and another near the weld, but these heat affected zones are discrete and separated by unaffected material. This confirms the belief that the area of the flaw was significantly less tough than the base metal due to heating during creation. However, it also suggests that the reconstruction process did not significantly affect the toughness in the area of the flaw.

The flaw itself is composed of two parts: a concave portion created by the torch, and a "flat" portion which was apparently grew after the initial defect was created. Crack growth is not uncommon or unexpected. The surface of the "flat" portion is covered with an oxidation product, but

Battelle informed the Task Force that it had performed no chemical analysis of the oxidation which would identify it as simple rust or another type of iron oxidation product. After reviewing its fractography and metallography, the Task Force agrees with Battelle that it is not possible to determine when the crack growth occurred. The mere existence of oxidation in the flaw, however, suggests that the crack was open to the atmosphere for some period, and the growth did not immediately precede the fracture. Furthermore, inspection suggests that the extension was a cleavage growth, not a fatigue growth. Lastly, the region of the flaw suffered embrittlement — a reduction in fracture initiation resistance — from nearby old and new welding.

The flaw's surface manifestations, however, would have been obscure. Visual observation, therefore, would have been almost impossible. The flaw's orientation and the existence of oxidation indicate that it grew within the plate's thickness and was exposed to the atmosphere at the inside surface of the tank. After many years of service, the inside surface becomes covered with residue which would hide such a minor surface manifestation. Similarly, even if STC had cut out the "old" weld the resulting torch-cut edge would have been so irregular and coarse that a surface manifestation would have likely been obscured. Of course, removing the "old" weld would have vastly improved weld quality and some or all of the defect could have been removed during joint weld preparation. These points will be discussed further later.

E. Geotechnical Investigation

1) Introduction

Early in the investigation the Task Force identified the foundation, or tank base, as a potential cause of the collapse. (Figure 4 is the plan for the foundation of Tank 1338.) Indeed, prior tank collapses have been traced, at least in part, to geotechnical causes. As a result, the Task Force conducted its own geotechnical investigation of the base. The procedures and methodology are set forth in greater detail since the work is original to this investigation.

2) Investigation

The Task Force's geotechnical investigation consisted of subsurface sampling and laboratory analysis of soil samples, gathering geologic information, and observing the geology of the area.

Five deep auger borings and twenty-two shallow auger borings were drilled. In addition, five test pits were excavated to examine soil conditions directly below the tank. (Figure 15 shows these sampling locations.) Rock samples (*i.e.* rock cores) were obtained from holes B1 and B2 only. These efforts were continously monitored by an engineer to assure that proper procedures were being followed.

To prevent cross-contamination and avoid the possibility of contributing to ground water contamination by inducing water into the hole while verifying the elevation of the top of rock, rock cores were obtained only from holes B1 and B2, which are outside the containment area and on the dikes surrounding Tank 1338. In addition, no water was used to remove cuttings in these or other holes. All holes that penetrated the contaminated ground typically were first cased, then sealed using a high solids, bentonite clay grout. This procedure involved augering through the contaminated ground, typically 18 to 24 inches deep, with 16 inch diameter hollow stem augers. At that point an 11 inch diameter steel casing was placed to the bottom of the hole. Volclay grout was then pumped into the hole filling both the area inside and the area outside of the casing. The grout mixture was allowed to set up over a 24 hour period before drilling resumed. In this manner, the groundwater was protected from additional degradation.

3) Testing

A complete battery of field and laboratory tests were conducted as part of the geotechnical investigation. For reasons of space the data obtained from the Task Force's geotechnical investigation is not reported here.

Two methods were used to gather soil samples. The first is called the Standard Penetration Test (ASTM D1586-84) with continuous soil sampling. This method was used on the five deep auger borings. A 2 inch outside diameter split-barrel

sampler, or "spoon", was used to obtain the soil samples. The sampler was driven its full length, 18 inches or 24 inches, into the earth for each sample with a 140 pound hammer falling freely over a distance of 30 inches. The number of blows required to drive the sampler each six-inch increment was recorded until refusal was encountered. Refusal is defined as a total of 50 blows being applied during any one of the six-inch increments. The borings were advanced using 8 inch Outside Diameter hollow stem continuous flight augers. Standard NX core barrels were used to drill into bedrock in holes B-1 and B-2. As stated earlier, rock was not cored in the other holes. Field measurements of unconfined compressive strength for cohesive soils were obtained from a pocket penetrometer. Rock Quality Designation (RQD) was recorded for rock cores. Samples were visually identified and catalogued in drill logs as they were obtained.

Six undisturbed samples were obtained using Thin-Walled Sampling (ASTM D1587-83) or "Shelby tube" technique. Since the raised foundation was built on fill, foundation material samples were taken at depths of two to four feet and natural ground samples at four to six feet depths. These were located from 1 to 10 feet from the outside edge of the base plate toward the center.

Triaxial Shear Tests, both consolidated-undrained (ASTM 2166-85) and unconsolidated-undrained (ASTM 2850-82), were conducted on six samples. These tests measure soil strength.

Both Nuclear Density (ASTM D2922-81, Method B) and Sand-Cone Tests (ASTM D1556-82) were utilized to determine the in-place density and moisture of the clay foundation beneath the gravel at eight locations. These test locations are identified as samples D1 thru D9. (See Figure 15.) Moisture-Density Relations (ASTM D698-78 Method A) were conducted at locations D1, D2 and D3 to compare with the in place density testing. Void Ratio Density (EM1110-2-1906 App. 2) and Moisture Content (ASTM D2216-80) tests were conducted in the laboratory to verify the field results.

A few Standard Proctor-Method A tests were conducted to verify the consolidation of the stone base. It was determined to be adequate. Consolidation tests (ASTM D2435-80) were conducted to obtain data on the soil's consolidation properties. This information was later used in consolidation calculations.

Permeability Tests with Back Pressure (EM 1110-2-1906 App. 7) using the triaxial testing device were conducted on two Shelby tube samples from borehole B5. This test measures the soil's resistance to water flow. Since soil conditions were similar throughout the site, these samples were considered representative of *in-situ* permeability conditions.

Atterberg Limits (ASTM D2435-80), the range of possible moisture content of the soil, were defined from five split-spoon samples and three Shelby tube samples. Actual Moisture Contents (ASTM D2216-80) were also defined for numerous samples.

Several other tests were performed and the data from them were primarily used to identify the soils encountered. Those tests were: Combination Sieve and Hydrometer Particle Size Analysis (AASHTO T88-81), Sieve Analysis of Soils (ASTM D422-63), and Specific Gravity (ASTM D854-83).

4) Results and analysis

a) subsurface lithology

The Task Force determined the lithology under the tank from available geotechnical information and the subsurface investigation. The surface elevation of the foundation is approximately 770 feet above sea level, some 43 feet above the Monongahela River. The static ground water table varied in depth from 18 feet to 22 feet below the surface. (Figure 16 shows the lithology under the tank.)

The area is underlain by rock strata belonging to the Casselman Formation of the Conemaugh Group. The Casselman Formation is characterized by the occurrence of thin limestones, thick channel sandstones, shales, claystones, and a lack of mineable coal. The site is located on an alluvial flood plain varying in thickness from 35 feet to 49 feet above bedrock. The bedrock at this site is a hard, grey, broken siltstone which appears to be a siltstone facies of the Morgantown sandstone. Bedrock is overlain by

flood deposits of stiff to very stiff brown silty sand and stiff to very stiff silty clay. The grain size of the sand and clay increases with depth.

b) investigation of failure modes

Many types of soil and ground conditions have been known to contribute to fluid storage tank failures; several research and reference papers have addressed those conditions. (Ref. 1, 8, 10, 13) Throughout the investigation into the collapse of Tank 1338 many, if not all of these soil related conditions, were hypothesized as contributing to this failure. The most serious and likely failure modes were specifically addressed by the Task Force's geotechnical investigation by applying data gathered through sampling, observation and testing to accepted scientific theories and principles and analysis techniques.

i) excessive total or differential settlement—

Settlement analyses were performed to determine the probable range of foundation settlements that may have been experienced beneath Tank 1338 during filling operations. Both elastic and consolidation type settlements were calculated with the assumption that all settlements would take place in the 28-foot thickness of silty clay and sandy clayey silt. It was assumed that the engineered fill which was placed above the ground surface, and the dense, clayey, silty sand with gravel which overlays bedrock, would exhibit insignificant settlements. Settlement calculations were performed to determine total settlements at the center and edge of the tank.

To predict the range of probable foundation settlements under the tank, the following four cases were analyzed.

Case 1: Full thickness (about 28 feet) used for both elastic and consolidation settlement calculations; percent consolidation settlement predicted by double drainage.

Case 2: Same conditions as Case 1, but percent consolidation settlement predicted by single drainage.

Case 3: Full thickness used for elastic settlement calculations, but only the thickness below the water table (about 10 feet) used for consolidation settlement calculations; percent consolidation settlement predicted by double drainage.

Case 4: Same conditions as Case 3, but percent consolidation predicted by single drainage.

Because the soils layers are consistent in thickness below the tank, only one soil profile was used for the four cases.

Different tank loadings based on Tank 1338 inventory records were used for the elastic and consolidation settlement analyses. A product depth of 34 feet, which was maintained for about 5 days, was used for the elastic settlement calculations, and a product depth of 21.5 feet, which was maintained for about 22.5 days, was used for the consolidation settlement calculations. The 5-day duration is believed to be a reasonable estimate of the time required for the elastic settlement to occur. The 21.5-foot depth and 22.5-day duration, which are considered the average depth of product and average duration of loading, were used for consolidation settlement calculations.

The parameters used for the elastic settlement analyses included a modulus of elasticity of 550 psi and a Poisson's ratio of 0.3. These values are averages for the full compressible soil thickness, and were derived from an evaluation of laboratory test data and published data.

The consolidation settlement analyses assumed three layers within the compressible soil thickness: (1) the heavily preconsolidated silty clay layer (11 feet thick); (2) the slightly preconsolidated sandy, clayey silt layer above the water table (7.5 feet thick); and (3) the normally to slightly preconsolidated sandy, clayey silt below the water table (9.5 feet thick). Since the laboratory values for the coefficients of compression, C_c, recompression, C_r, and consolidation, C_v, were quite similar for all three layers, the average of the laboratory values was used in the analyses. These average values were: $C_c = 0.17$; $C_r = 0.028$; and $C_v = 0.039$ in ^{2}/min.

Void ratio versus pressure curves, which resulted from laboratory consolidation tests, were interpreted by Casagrande and Schmertmann techniques; these curves showed that all three

layers are preconsolidated to a higher load than the load resulting from the filling of Tank 1338. Based upon laboratory test data, it was assumed that the heavily preconsolidated silty clay layer was preconsolidated to 11.6 ksf, and that the sandy, clayey silt layer, both above and below the water table, preconsolidated to 4.6 ksf.

Settlement analyses results indicate that only minor foundation settlements should have occurred beneath Tank 1338 as a result of filling operations; settlements should have ranged between approximately 1.3 and 1.6 inches, as shown in the table below.

The occurrence of only minor foundation settlements is attributed to the following conditions: (1) although a 28-foot thickness of silty clay and sandy, clayey silt is present beneath the tank, the material has been preconsolidated in the past by a fluctuating groundwater table, and is not greatly affected by the weight of the tank and product, and (2) the load of the tank and product were only imposed on the foundation soils for a short period of time, resulting in only a small percentage of consolidation settlement.

Prior to the construction of Tank 1338, an older riveted storage tank was located at this site with its center about 27 feet east of the new tank with dimensions of 115 feet wide by 40 feet high. While not precisely congruent, the floor of Tank 1338 substantially overlapped the base of the replaced tank.

After the tank floor was removed, the crushed rock foundation under the tank was surveyed by a Pennsylvania Department of Transportation survey crew. (Figure 17 is a contour map compiled from the results of the survey.) The greatest difference in elevation measured between the center and edge, was one foot. Tanks with diameters of 120 to 150 feet have been known to withstand differential settlements of 1.2 feet to 4.0 feet without any adverse effect on tank behavior. If settlement did occur, it did so uniformly causing little effect to the structure. It was also evident that product gushing out of the ruptured tank caused erosion which contributed to the low point of 1.4 feet. For the reasons cited above, appreciable settlement is not considered to be a contributing factor to the tank failure.

If minute differential settlements did occur, the effects of increased circumferential tensile stresses are minimal. Computer analysis performed by NBS shows that localized differential settlements of .5 inches would produce an increase in tensile stress of about 500 psi at the location of the flaw in the tank shell. NBS considers this increase in stress to be trivial; the Task Force concurs. A more detailed discussion of this computer analysis can be found in the report of NBS.

ii) base and edge, or localized shear failure—

Another failure made considered was base and edge or localized shear failure. This failure mode is the sliding away of a portion of the sloped foundation edge and/or a portion of the natural ground under the sloped foundation due to the application of forces which are greater than the existing shear forces holding the soil in place. Results from triaxial shear tests were used in this analysis. The cohesion, (c), resistance of the soil against shear along a surface which is under no pressure, and angle of shearing resistance, the plane along which a sample subjected to transverse loading will fail, were similar in both the consolidated undrained (CU) and unconsolidated undrained (UU) test results. Cohesion ranged

Table 2

Settlements (Inch)						
	At the Center of the Tank			At the Edge of the Tank		
Case	Elastic	Consol.	Total	Elastic	Consol.	Total
1	1.2	0.4	1.6	0.6	0.3	0.9
2	1.2	0.2	1.4	0.6	0.1	0.7
3	1.2	0.3	1.5	0.6	0.1	0.7
4	1.2	0.1	1.3	0.6	0.1	0.7

from 1.2 KSF to 2.0 KSF and ∅ varied from 14.5°F. to 26°F. Six Shelby tube samples were used in the triaxial tests; three from the raised foundation fill material (clay) at depths of two to four feet and three directly below the fill in natural ground (clay) at depths of four to six feet. Since water runoff in the containment area was controlled by a gate valve, water may have backed up and inundated the raised foundation. This circumstance was addressed by performing a triaxial shear test on a saturated sample. The saturated sample test yielded the lowest results (∅ = 0°F. and c = 1.9 KSF). These results were used in the computer calculation of the stability of the foundation's edge against shear failure.

PCSTABL5, a microcomputer program that calculates the factor of safety against shear failures using a two-dimensional limiting equilibrium method, was employed. PCSTABL5 utilizes the two simplified analytical approaches: the Bishop and Janbu methods of slices. All factors of safety against failure calculated were above acceptable limits; the lowest factor of safety was equal to 2.74.

iii) shallow soil saturation—

Five test pits were dug with a hydraulic excavator to visually examine the raised foundation conditions below the surface. (Figure 15 shows the location of these test pits.) All visual conditions were similar in that only the top 1/4 inch to 1/2 inch of the clay portion of the foundation was soft or wet. Water and product could be seen flowing, in some instances ponding, beneath the geotextile on the surface of the clay. The remaining two to three feet of foundation material appeared dry and well compacted. Density and moisture content from nuclear gauge and sand cone results support these observations.

iv) subsidence—

Subsidence was not related to the tank failure for several reasons. The mineable coal seams in the area would not have affected the foundation. They are the Pittsburgh coal seam, which is at a higher elevation, and the Upper Freeport coal seam which is located at least 400 feet below the site and not minable at this location. As mentioned earlier in this report, any appreciable settlement or subsidence that might have occurred did so uniformly, resulting in no adverse effect on the tank structure.

v) erosion—

Erosion patterns on and around the tank foundation were investigated by the Task Force with the assistance of a hydraulics expert from ATLSS. It was evident that gullies, potholes and sheet erosion patterns were the result of the outflow of product. The possibility of an initial base plate failure was raised during the course of the investigation. Any erosional evidence of an initial base failure, however, would have been destroyed by the high shear stresses created by the outflowing fuel from the shell fracture. Thus the erosion patterns provide no evidence of the foundation's involvement in the collapse.

d) conclusion

The Task Force concluded from this geotechnical investigation that neither the foundation, nor the procedure used to construct it, were directly involved as the primary mode of failure. The Tank 1338 foundation was found to be solid and reasonably level. The investigation showed that settlements, total and differential, were not excessive. Soil characteristics, determined through various analyses, were not conducive to a base or edge shear failure. In addition, there was no evidence showing subsidence from mining or voids beneath the base plate. Finally, the foundation was well compacted and dry and showed no evidence of being unstable. This was borne out by testing and analysis as well. In addition, the foundation was built in accordance with the drawing provided to ZEI by Ashland.

The Task Force supplied its raw geotechnical data to NBS. NBS independently analyzed the raw data and obtained results very similar to the Task Force's. NBS also concluded that the foundation was stable and did not contribute to the collapse of Tank 1338. Battelle conducted an independent geotechnical study. The results of that study are consistent with those reported above. Battelle, too, concluded that the foundation was sound. The reader should refer to the reports of Battelle and NBS for a complete technical discussion of their geotechnical efforts.

F. Other Theories and Failure Scenarios

During the course of the investigation numerous theories or scenarios for the collapse of Tank 1338 were proposed in the public arena and in private Task Force interviews and discussions. The Task Force has tried to identify and evaluate each.

1) Floor failure

The possibility that a failure in the floor either caused or contributed to the collapse of Tank 1338 was presented to the Task Force early in the investigation. This theory was investigated in light of the typically high stresses experienced at the bottom of the shell and prior floor related tank collapses. A strikingly similar, brittle failure of an oil storage tank in 1972 was initiated by the failure of a portion of the weld connecting the floor to the shell. (Ref. 2) (The 1972 failure is shown in Figure 11.) Other collapses in Europe in the late 1960's and early 1970's have also been attributed, at least in part, to floor weld failures. (Ref. 1)

Upon closer examination, however, these other collapses are distinguishable. The chevron marks in the 1972 collapse pointed to a defect in the floor-to-shell weld. However, the chevron marks on Tank 1338 point to a flaw in the shell. The European tank collapses are thought to have been caused by a leaking floor which in turn caused a loss of foundation integrity. The foundation of Tank 1338 has been determined to be sound. Furthermore, no physical evidence which indicates initial floor failure has been uncovered. The floor welds failed because of the shell fracture, not *vice-versa*.

During the event, some floor welds failed, partially separating a wedge shaped piece of the floor from the rest of the floor. This is not considered significant. As the fracture moved around the tank's circumference at the base, it opened the weakest welds. The broken floor plate welds were at least as weak as the floor to shell welds. Nevertheless, the shell eventually broke free from the floor and was propelled over 100 feet.

2) Roof failure

Failure of the roof was also suggested as a possible cause of the collapse. This theory was fueled, in part, by the badly bent and twisted columns and other structural members strewn about the grounds, the distressed condition of the roof after collapse, and failure of practically every welded connection. (Photos 18 and 19 show these effects.)

The roof system of a tank like Tank 1338 is not intended to carry any load other than self-weight and environmental loading, *e.g.*, snow. It plays no role in the structural integrity of the tank. In fact, tank roofs are designed to be frangible, that is, to fail before other joints in the unlikely event that a pressure "head" develops in the tank. Similarly, the supporting structure only exists to support the roof not the tank. Many of the members used in the roof support structure were slender or prone to buckling.

Nevertheless, roof or roof structure failure is a very remote possibility. The NBS computer model of the tank showed that stresses in the shell near the roof were very low—trivial, in fact. Despite the slenderness of many members, low loads and lateral support provided by the product made it highly unlikely that any of them failed. Even if one or two failed, the supporting structure was redundant and the remaining members should have been able to carry the load. Finally, the tank structure *per se* is independent of the roof system. Barring a sudden total collapse, the adequacy of the roof and supporting system has no effect on the tank's ability to contain fluid. There is no evidence supporting a sudden total roof system collapse.

The distressed condition of the roof and supporting members was simply an effect of the sudden release of almost 4,000,000 gallons of No. 2 fuel oil. An almost unimaginable amount of energy was unleashed when the tank collapsed. The energy released was sufficient to mangle the shell of Tank 1338 virtually beyond recognition, damage one nearby tank so badly that it was taken out of service, demolish a small cinder block building, and disperse the product substantial

distances. The observed damage to the roof and members is quite consistent with this massive release of energy.

3) Pressure accumulation

It had been suggested that the vents on Tank 1338 had become clogged or were inadequate. This allowed a pressure "head" to develop in the tank, and the additional loading from such pressurization caused the collapse.

The Task Force investigated this theory and found it to be without merit. The tank was vented by three eight-inch diameter pipes. The ends of the pipes were covered with mesh and bent, like candy canes, to keep out debris which might clog them. (Photos 20 and 21 are photographs of the vents.) Shortly after the collapse members of the Task Force examined the vents and determined that they were open and operational, and contain no mechanism to close them.

At the Task Force's request, ATLSS performed calculations on the potential pressure accumulation if a blockage did occur. This calculation was based on the known pumping rate into the tank and assumed that only one of the three vents to be functioning. Classical fluid mechanics analysis showed that the pressure accumulation even in this scenario would be trivial. The Task Force has concluded that inadvertent pressurization played no part in the collapse.

4) Static electricity

Static electricity often accumulates in storage tanks during filling. Consequently, the possibility that an accumulation of static electricity may have occurred in Tank 1338 and caused the collapse by a sudden discharge was examined.

The Task Force discussed this phenomon with API. Static electricity does accumulate in tanks during "splash" filling of volatile petroleum products. Tank 1338 was being filled with No. 2 fuel oil, a non-volatile product, and was being filled from the bottom, not "splash" filled. In addition, such static discharges invariably cause a fire; no fire occurred at Floreffe. Thus, there is no evidence suggesting that static electricity build-up played a part in the collapse of Tank 1338.

5) Thermal stresses

There was much speculation that a significant temperature differential existed between the atmosphere and the product, resulting in thermal stresses in the tank which caused the collapse. Thermal stresses may have contributed to some past tank failures. (Ref. 5)

The temperature of both the product stored in the tank and the product entering it on January 2, 1988, was approximately 46°F., and the air temperature at collapse was approximately 26°F. NBS performed a heat-exchange analysis which calculated the shell temperature to be 38°F., with no appreciable thermal gradient across the shell wall. The floor was likely the same temperature as the product. NBS concluded that the 8°F. difference between the shell and floor would not result in significant differential expansion, and, thus, no significant thermal stresses. The Task Force has reviewed and adopts this analysis and the conclusion that no significant thermal stress was developed. The temperature of the tank wall was, of course, significant in terms of toughness.

6) Spring or water pipe rupture

Shortly after the collapse there was speculation that water had been flowing under the tank base from a ruptured pipe or spring and caused or contributed to the collapse. This speculation was fueled, in part, by reports of air bubbling through product which filled the dike after collapse. Although this postulated failure mechanism is not well developed, it appears to conjecture that water affected the foundation by freezing and thawing or simply weakened it by saturating it.

Based on numerous site visits, in various weather conditions, interviews, sub-surface investigation and review of utility drawings the Task Force could find no evidence of any spring or water line running directly under the Tank 1338 foundation. As discussed above, the foundation was determined to be stable. The foundation was surveyed and found to be reasonably level. The hypothesis is inconsistent with all available empirical data and observations.

7) Fatigue

Fatigue is a failure caused by repeated loading and unloading of a structure. Since storage tanks are subject to constant filling and emptying it was suggested that the collapse may have been caused by a fatigue failure.

The fracture surface, however, does not support this hypothesis. Fatigued metal has distinctive appearance and markings. This appearance is characterized by a flat fracture surface with visible clam shell markings where the crack incrementally propagated and arrested. This is in contrast to the triangular chevron marks which characterize a brittle failure surface and were observed here. Further, there were no reports of cracks or leaks in the tank prior to the date of collapse. Thus, the physical evidence clearly refutes the possibility of a fatigue failure.

8) Strength failure

It was widely assumed that Tank 1338 was simply overstressed since January 2, 1988 was the first time that it was filled to capacity. This postulate was also considered.

A computer analysis performed by NBS showed that the maximum static stress in the tank from product was about 13.1 ksi. This is significantly less than the yield stress, and well below the ultimate strength of the material. This stress level is not sufficient to cause the tank to collapse. Furthermore, as discussed earlier, a stress failure occurs gradually, and gives "warning" through gradual deformation. All evidence points to a sudden collapse in this case. Finally, if a strength failure occurred the fracture location would experience a reduction in cross-sectional area, with no particular pattern evident on the fracture surface. There was no reduction in area at the fracture surface on Tank 1338, and chevron marks emblematic of brittle failure were present. Thus, neither analytical nor physical evidence suggests that a strength failure occurred.

9) Steel crystallization

It was suggested in the media that the steel in Tank 1338 had crystallized over time, and this crystalization somehow weakened the material. This theory appears spawned by a general belief that the tank was inherently infirm due to its age.

The Task Force has investigated this possibility and found it to be meritless. Steel is a crystalline material; its structure does not change over time. The crystalline structure is revealed by, and consequently is an indication of, a brittle failure. There is no crystalline appearance when steel fractures in a ductile manner (*i.e.* strength failure). Nevertheless, observation of the crystalline structure of Tank 1338's plates led to conjecture that crystals had formed and weakened the material. This conjecture represented an example of confusing cause and effect. Age *per se* does not alter the steel, but steel manufactured many years ago had significant shortcomings even when new.

10) Pressure spike

In the course of the investigation it was suggested that a "pressure spike" might have developed during the filling of Tank 1338. A "pressure spike" is an abrupt increase in flow caused when a blockage is cleared, which in turn creates additional pressure in the tank. Such blockages are sometimes caused by jelling of diesel fuel in cold weather.

The tankerman who was pumping into the tank at the time of the collapse did not observe anything unusual. He was pumping at a steady rate, and observed no pumping irregularities. He did not even know that the tank had collapsed until he got the news from an Ashland employee over the radio. At the time of the collapse, the tank was nearly filled to its four million gallon capacity; it was being filled at less than 2200 gallons per minute. It is extraordinarily unlikely that a "pressure spike" from this limited product flow could impart enough energy to affect the tank given the inertial effects of the great mass in the tank. There is no evidence supporting this theory.

11) Vacuum

It was also suggested to the Task Force that a vacuum was created on the tank by draining or transferring product from it. Presumably, the ventilation system was inadequate for the rate of product removal, negative pressure accumulated, and eventually caused the collapse.

The Task Force can find no evidence supporting this theory. As discussed earlier, the ventilation system was more than adequate. In

addition, if a vacuum failure had occurred the collapse scene would have looked much different. The tank would have imploded or collapsed in on itself. The collapse scene itself clearly refutes this possibility. Finally, though product had been transferred from Tank 1338 to another tank during the filling operation, there is no evidence of any transfer at the time of the collapse.

G. Materials Analysis

1) Shell steel

a) background

Over the years, a variety of steels have been used for the construction of oil-storage tanks. In the earlier days of riveted tanks, it was common to use ASTM A 10 or A 7 grades of steel. In those days, there were not stringent requirements for the carbon and manganese contents, but limits existed for sulfur, phosphorous, nickel and silicon. Strength levels were often expressed in terms of yield strength and tensile strengths, the latter depending on the thickness of the plate or sheet. Percent elongations were also specified for these steels for 2 and 8 inch gage lengths. Manufacture of these steels was by the open hearth or electric furnaces. Later, the basic-oxygen process was also allowed, although not for shell plates.

With a fuller understanding of welding processes, later specifications, such as ASTM A 537, established more complete chemical requirements. It contains upper limits on carbon content and manganese levels, chromium and molybdenum. Moreover, the carbon and manganese contents were linked through a carbon equivalent formula. ASTM A 283, recommended in API-650, specifies chemical composition limits for phosphorous and copper, as well as strength and ductility requirements. However, no limits for carbon, sulfur, manganese, or other elements are specified.

b) testing and results

Battelle performed exhaustive testing to determine the chemical composition and mechanical properties of the steel and weld material used in Tank 1338. NBS also performed tests on the material's mechanical properties. The Task Force has reviewed and is satisfied with the tests and procedures used and adopts the results of the Battelle and NBS testing and analysis. The reader should refer to the reports of Battelle and NBS for a detailed discussion of the testing and analyses performed and results. With a few limited exceptions the results will not be reported here, and those reported have been included for illustrative purposes.

The results show that the properties and composition of the steel used in Tank 1338 are typical of steels manufactured at the time it is believed to have been built. NBS determined yield stress to be between 34.5 ksi and 33.0 ksi, Tensile Strength between 67.3 ksi and 66.9 ksi. Elongation was approximately 34%. Thus, the strength is more than adequate for this application.

Table 3 - Summary of Charpy-V-Notch Test Results * — Energy Absorbed (Ft.-lb.)

Average Temperature	First Course	First Course	Second Course	Second Course
(F)	(Transverse)	(Longitudinal)	(Transverse)	(Longitudinal)
160.2-160.0	37.5	53.5	32	38.5
121.5-121.4	27.5	33.5	21	20.3
80.4-79.7	17.3	13.0	9.8	11.5
57.8-35.4	9.0	8.8	6.0	6.4
40.3-39.8	5.5	6.2	4.8	4.4
21.2-20.0	4.0	6.1	4.2	3.7

** All values are the average of 2 or more specimens.*

The notch-toughness results are also typical for steels of that era. Table 2 shows the results of Charpy V-notch tests for samples from the first and second course. For simplicity, only the energy results have been reported. Transition temperature, defined as the temperature at which the specimen exhibits a Charpy V-notch toughness of 15 ft.-lb., was determined by NBS to be between 80°F. and 100°F. Thus, the temperature at which the steel would begin reacting brittlely according to the API-650 standard was far above the actual temperature on January 2, 1988, or, for that matter, most of the year in Western Pennsylvania. The steel used in Tank 1338 fares poorly when compared against A-36, one of the steels allowed by API-650 for tank construction today. A-36 has a transition temperature of about 20°F.

c) discussion of results

The material in Tank 1338 was manufactured in the late 1930's or early 1940's. Therefore, the steel was likely made using an open hearth process which typically resulted in steels with high levels of sulfur and phosphorus, perhaps 0.03-0.05%. High levels of phosphorus and sulfur are accompanied by extremely low notch toughness. However, the actual composition of the tank shell steel is atypical. The levels of sulfur (.017 to .031%) and phosphorus (.011 to .016%) are lower than expected. Thus, the low toughness of the Floreffe steel was not caused by its sulfur and phosphorus content.

Instead, it probably was the result of the deoxidation process, known as killing, and resulting ferrite grain size. Both aluminum and silicon have been used to kill steel. Aluminum killing helps to increase toughness by reducing the ferrite grain size and increasing the cleanliness of the steel. Grain size is a microscopic indicator of toughness. Silicon killing, on the other hand, does not refine ferrite grain size or increase toughness. However, the low silicon content (.001 to .025%) and mere trace levels of aluminium indicate that the steel in Tank 1338 was not killed at all. Rather, it was a "rimmed" steel, one in which no intentional alloys have been added to remove the dissolved oxygen. The dissolved oxygen is removed through reactions with the carbon in the steel, forming CO_2. The gas is partially entrapped in the solid steel, causing internal spherical voids. Rimmed steel in general has a large ferrite grain size and consequently low Charpy V-notch toughness values.

In addition to the deoxidation practice, the ferrite grain size can be reduced by lowering the finishing temperatures used in the hot rolling of the steel. The finishing temperature is the temperature at which the steel is rolled. The lower the finishing temperature, the finer the ferrite grain size and, consequently, the greater the toughness. The facilities used to hot roll steel fifty years ago provided relatively inaccurate temperature control, and the rolling mills themselves could only deform the steel when it was hot. Modern steel processing facilities, on the other hand, have been improved so that the temperature can be controlled more accurately and the rolling mills today are more powerful, allowing deformation when the steel is at a lower temperature. The net effect is that steels can be finished at lower temperatures, resulting in smaller ferrite grain size and greater toughness.

Steels used today have better toughness properties and lower transition temperatures for any or all of the following reasons: (1) aluminium killing; (2) reduction of the level of impurities (especially sulfur and phosphorus); (3) controlling variables in the steel making process (*e.g.*, low finishing temperature); and (4) slow cooling to control ferrite grain size. Several steels are allowed by API-650; most require fine grain practice (*i.e.* aluminum deoxidation, low finishing temperatures). API-12C, which was replaced by API-650, permitted steels which were not made to a fine grain size practice, and therefore had lower toughness.

The general design practice today is to choose a steel depending on the geographical location. If the lowest temperature a given region is -10°F., then the material used in that region should have a Transition Temperature of less than -10°F. The API-650 procedure is similar. The standard specifies a a design temperature which equals the Lowest One Day Mean Temperature (LMT) plus 15°F. The LMT for the Pittsburgh area is -10°F., and therefore the design temperature is 5°F. The design temperature must be greater or equal to the Minimum Permissible Design Temperature (MPDT). The MPDT is defined in API-650 and depends upon the type of material and

thickness. The MPDT for the steel in Tank 1338 cannot be determined because that material is not specified in API-650. Since Charpy V-notch testing is required if the MPDT cannot be met and since the lowest Charpy test values are approximately 15 ft.-lb., it is presumably related to the transition temperature. The calculated 15 ft.-lb. transition temperature for the Tank 1338 steel is between 80°F. and 100°F. This means the tank should not have been used in climates where the temperature dropped below those tropical levels. The tank's use was clearly well below standard. Thus, low toughness properties, one of the three requirements for a non-impact brittle fracture, could be expected during the vast majority of the year.

2) Welding

Though it did not figure prominently in Battelle's report, the welding on Tank 1338 attracted a great deal of public attention and was a matter of great interest to the Task Force. A discussion of welding issues follows.

a) welding development

Welding is a relatively recent development in construction technology. The quality and uses of welding have increased dramatically over the years. It long ago replaced riveting as the preferred connection method.

Improvements in welding have improved the toughness of the welds. Tougher weld materials and control of the reactions between fluxes or atmospheres have resulted in welds with good toughness in temperatures as low as -50°F. The use of electrodes coated with calcium carbonate ($CaCO_3$) rather than cellulose results in a basic slag with low hydrogen, thus eliminating hydrogen cracking, a once common problem.

In addition, the training and testing of welders has improved significantly. According to API-650, all welders working for a given manufacturer must pass a welder qualification test in which the welder must demonstrate ability to make acceptable welds. Thus, all welders should be able to make acceptable welds.

A welding procedure qualification, also required by API-650, specifies that the manufacturer shall conduct tests to demonstrate that the processes used will make welds conforming to the specified requirements. These weld procedures must produce weldments whose mechanical properties are adequate for the design stresses. The requirements for welding procedures and welder qualifications are contained in Section IX of the ASME Code. The requirements of ASME Section IX are very definitive and should insure that the welding procedures are adequate to make safe and long lasting storage tanks.

Improved weld inspection procedures, including radiography, ultrasonics, and visual inspection, have contributed to improved weld quality by forcing the welders to make acceptable welds on the first attempt. If defective weldments are found, the welds must be removed, rewelded and re-inspected before the weldment is accepted. The improved inspection procedures have made it uneconomical to make unacceptable welds which must subsequently be repaired and re-inspected before the weldment is accepted. All of these added steps increase the cost of manufacturing, and, thereby create an economic incentive to make better welds and decrease the amount of repair work.

Radiography, though in existence for many years, was at first considered to be unreliable and was used as a secondary testing method, after sectioning. Sectioning is the physical testing of cylindrical samples of actual welds. Since then, radiography and other non-destructive techniques have replaced such destructive methods. Improvements in both radiography techniques and qualification of radiographers have been responsible for making it the preferred method of testing welds.

b) testing and results

Both Battelle and NBS have determined, as discussed above, that the flaw which initiated the brittle failure of Tank 1338 was wholly located in the base metal, not in weld material. After reviewing the fractography, photographs and other data the Task Force agrees. The basis for this is more fully developed in the reports of Battelle and NBS. The reader should refer to them for more details.

Interestingly, the measured Charpy V-notch toughness of both "old" and "new" welds from Tank 1338 is much higher than the base metal notch toughness. Table 3 shows the results of Charpy V-notch tests performed on weld material. The fracture ran across welds, but did not follow any. This is probably due to the toughness of the welds being greater than that of the base metal. The quality of welding, therefore, did not cause or contribute to the failure.

c) discussion of results

While the welds did not contribute to the collapse of Tank 1338, their quality should not be ignored. After reviewing radiographs and actual samples of welds from the tank, the Task Force has concluded that the quality of welding on the tank, both original and recent, was deficient. NBS has also reached this conclusion in its report. The welds were so laden with defects that personnel at NBS were unable to locate enough sound weld material to perform certain mechanical tests. (Photo 17 is a photograph of a weld from Tank 1338 which shows five weld defects within a single weld cross-section.) Such defects themselves are flaws that could have caused brittle failure.

Most of the factors identified above which have lead to improved welding quality were not present or were undermined on this job. Proper training of welders and welding procedures are cited reasons for improvements in weld quality. However, STC had no welding procedures and questions can be raised about its welder qualifications. In addition, effective inspection techniques, another factor which has contributed to improved weld quality, were not implemented on this job. An inadequate number of radiographs were performed, and most of those showed rejectable welds. These results, however, were effectively ignored. The radiography was done at the end of the job, causing Ashland to lose the benefit of the radiographer's presence to keep welders attentive to their work. Finally, Ashland did not require defective welds to be repaired, undermining the final reason cited above for improved weld quality—economic benefit. Many of these topics will be revisited in greater detail later.

H. Compliance with Applicable Standards and Codes

Both industry practice and the contract between Skinner Tank Company and Ashland dictated that the current edition of API-650 was to have been followed in the reconstruction of Tank 1338. In many respects, though, neither the spirit nor letter of API-650, Seventh Edition, was honored. Both STC and Ashland failed to comply with certain mandatory provisions of the standard. The terms of other sections, however, allowed Ashland to take certain steps or impose certain requirements on the project. In virtually all cases it failed to do so. Both situations will be identified in the following section-by-section discussion of excursions from the standard. The numerical designation is to the applicable section of API-650. The tank builder, in this case, STC, is the manufacturer as that term is used in the standard.

Table 4 - Comparison of Charpy-V-Notch Results from Weld Metal and Base Metal

Material	Temperature (F)	Average Energy Absorbed (ft.-lbs.)
"New" Weld	40	No results
"New" Weld	71	86
"Old" Weld	40	21.8
"Old" Weld	71	23.2
First Course Base Metal	40	5.9
First Course Base Metal	60	9.0
First Course Base Metal	80	17.3

1.1.10 Data Sheet—This section states that the purchaser shall provide the manufacturer with a Data Sheet, found in Appendix L, defining the tank it wants and other design parameters. The manufacturer, in turn, shall return a copy of the sheet to the purchaser with the tank's actual specifications upon completion of the job. The Data Sheet is a concise statement of the tank's design criteria, composition and physical characteristics. Ashland did not provide Skinner Tank with a Data Sheet, and Skinner Tank did not give one to Ashland. STC does not generally use the Data Sheet in its business.

1.2 Compliance—This section states that the manufacturer is responsible for compliance with the provisions of API-650. When the fabricator and erector are separate entities, Section 8.2 assigns responsibility for complying with the standard to the erector. Skinner Tank clearly failed here. Its employees, including foremen and welders, were not well acquainted with API-650, or other relevant codes. Welding procedure documentation did not satisfy the requirements of API-650 and Section IX of the American Society of Mechanical Engineers, Boiler and Pressure Vessel Code (ASME Code). The ASME is an industry trade group which establishes codes and specifications for the design and construction of pressure vessels, piping, boilers and other mechanical equipment. Many other provisions of API-650, which are discussed more fully below, were not satisfied as well. STC had no formal written Quality Assurance or Quality Control program. It did not employ inspectors; the job crew consisted of welders, laborers and a foreman.

2.1 Material—All material used in tanks is to be identified as conforming to one of the specifications listed in Section 2 or identified through testing. Appendix N requires exhaustive mechanical and chemical testing and analysis. Skinner Tank neither identified the material used in the tank nor identified it by testing. Without knowing the material or its properties it is not possible to design, qualify, or weld with certainty.

2.2.8 Impact Testing—The purchaser may require the impact testing (Charpy V-notch) of plates to determine their toughness. As discussed more extensively elsewhere, the collapse was caused by a brittle fracture, a failure mode associated with low-toughness materials. Steels produced in the era of the tank, assumed to be circa 1940, typically had low-toughness properties. Ashland, therefore, should have been aware of the possibility that it was dealing with a low toughness material and taken steps to evaluate the steel in this regard. It did not, though, require any toughness testing.

2.8 Welding Electrodes—This section specifies the electrodes to be used with materials of certain tensile strength. STC did not know the mechanical properties of the material used in the tank. Nevertheless, it assumed that the material was "mild steel" and used the electrodes it typically uses. Skinner Tank had no basis for making this decision prior to or during construction.

2.9 Toughness Requirements—This section specifies minimum toughness requirements for all shell plates, reinforcement plates, and other enumerated steel parts. The material must meet specified Charpy V-notch toughness requirements at the design temperature. The design temperature is defined as 15°F. above the lowest one day ambient mean temperature, which is defined for each area of the country in API-650. In the case of Tank 1338 the lowest one day mean temperature is -10°F. and the design temperature 5°F. The Minimum Possible Design Temperature cannot be determined from API-650 Figure 2-2 because the steel used in Tank 1338 is not one of those listed in the standard. Still, the design temperature, 50°F., is far less than the material's calculated 15 ft-lb Charpy transition temperature, 80°-100°F.

If testing was performed under Section 2.2.10, the material would fail miserably. Analysis by NBS showed that the Charpy V-notch toughness at approximately 20°F. is 6 ft-lb or less. This is far less than the minimum acceptable value in Table 2-2, 13 ft-lb. Though testing is not required if the material meets certain criteria, the analyses of NBS and Battelle showed that the steel used in this tank could not meet the standard.

3.1.5.3 Lap Welded Bottom Plates—This section requires that the edges of bottom plates be fitted and lap welded to provide a level bearing surface where the shell joins the base. Observations by the Task Force after the collapse showed

that these joints were not constructed in accord with API-650. (Figure 18 is a sketch of this joint.) This is significant because if the joint is not properly prepared a discontinuity, or flaw, is produced. Though apparently not the cause of this collapse, a discontinuity or flaw of this sort can provide a "stress riser" or initiation point for a brittle fracture. Weld detail discontinuities have caused brittle fractures of tanks in the past. (Ref. 2, 3, 5) This detail is typically used in the industry.

3.2 Design Considerations—The purchaser is required to specify design considerations to the manufacturer. These design considerations include: design specific gravity, corrosion allowance, design wind velocity, and external loads. Ashland did not specify these criteria to STC. The Task Force uncovered no evidence in its investigation that Ashland or STC ever discussed or gave any thought to these design considerations.

3.3.1 Foundation Capacity—The adequacy of the tank's foundation is the purchaser's responsibility. Ashland's design and construction procedures did little to assure an adequate foundation. The foundation was apparently designed by Robert G. Cruickshank of the Design Group. However, he has limited recollection of his role in designing it. Though Ashland has devised standard tank foundation designs, the foundation of Tank 1338 was not a standard design. No calculations for the foundation exist; none may have been done. Cruickshank does not know what design parameters he was supplied by Facilities Engineering. Cruickshank, in turn, provided an unchecked sketch to Walters. Apparently without thinking this odd, Walters drafted the sketch and issued it to the contractor for construction.

The foundation for Tank 1338 was the first tank foundation that this contractor, Zimmerman Excavating, Inc. had built; ZEI was unfamiliar with Appendix B of API-650. (Appendix B is a non-mandatory part of API-650 dealing with tank foundation design and construction.) However, it simply followed the drawing. Since the prior tank foundation experienced drainage problems, the new foundation was raised by adding fill. To ensure a solid base, Solar Testing was hired to check the compaction after each lift was applied. STC identified some spots where the compaction was inadequate. However, it is not clear if Zimmerman fixed these inadequately compacted spots prior to adding the next lift; they were not specifically tested. Neither the project engineer, Walters, or the terminal manager, Morgan, exercised any effective control over the construction of the foundation. Walters did not visit the site during this phase of the construction. Morgan was present, but exercised no authority. At least tacitly, each assigned the responsibility for oversight to the other.

3.3.4 Weld Hardness Evaluation—The purchaser may specify tests to determine the hardness of the weld metal and heat affected zone. The Task Force has uncovered no evidence that such testing was requested or performed.

3.6 Shell Design—This section contains shell design criteria and analysis methods. The Task Force has uncovered no evidence that any design or analysis work was done. The tank held No. 6 fuel oil, a denser product, at Whiskey Island for some period prior to its relocation, but may not have been designed for that product, and inventory levels are unknown. Ashland does not possess the tank's original design criteria, and the use of WI-16 cannot be documented for is entire life. As far as is known, it was always used in heated service for No. 6. In any case, the tank may not have satisfied the requirements of API-650, Seventh Edition, regardless of the product it was originally designed to hold. API-650 and its predecessor standards have been revised many times to reflect changes in technology and knowledge. Table 1 shows how design stresses have changed. Section 3.6.1.1 states that the thinnest shell plate that may be used in a tank the size of Tank 1338 (120 foot diameter) is 5/16". The top course of Tank 1338 contained shell plates of lighter gauge.

3.6.1.8 Shell Drawings—This section requires the manufacturer to provide a drawing for each shell course to the purchaser. STC did not provide these drawings to Ashland. This is not a purely academic requirement. Tank drawings are valuable for maintenance, repair and inspection.

3.7 Shell Opening Design—This section contains criteria for designing shell openings such as pipe inlets or manways. The Task Force has uncovered no evidence that the compliance of any of the reused WI-16 openings with these criteria

was investigated, or that these requirements were utilized to design shell openings added during reconstruction. The only relevant document is a sketch supplied by Walters showing the location of required shell openings to Skinner Tank. However, apparently no design work was performed for these openings. Past tank failures have been traced to poor shell opening designs.

3.10 Roof Design—This section contains criteria for the design of the roof and supporting structure. As with 3.6 and 3.7 above, compliance with the current standard should have been ascertained; there is no evidence that it was. No drawings of the roof supporting structure exist, and the crew that dismantled the tank did not reassemble it. Unlike the shell plates, STC has not claimed that it marked the roof structure members for reassembly. There is little guarantee that the roof structure was either reassembled as it previously had been or in compliance with API-650, Seventh Edition.

4.1.1.1 Workmanship—This section states that "[t]he workmanship and finish shall be first class in every respect and subject to closest inspection by the manufacturer's inspector whether or not the purchaser waives any part of the inspection." The workmanship on Tank 1338, at least with respect to welding, was sub-standard.

5.2.1 Welding Details-General—API-650 requires that all welding shall be performed in accordance with Section IX of the ASME Code. In several ways STC did not comply with Section IX of the ASME Code. Section IX requires manufacturers to maintain Welding Procedure Specifications (WPS) which tell welders how to make welds. It also requires welders to be qualified. Apparently, STC had no Welding Procedure Specifications and its welder qualifications raise questions. These topics will be discussed in greater detail below.

5.2.2.2 Bottom Plate Welding—This section recommends that the manufacturer specify to the purchaser its proposed sequence for welding bottom seams. The Task Force uncovered no evidence that this was done. In fact, Larry Skinner's description of STC's bottom welding procedure differed from the actual practice at Floreffe described by Leonard Fritchman. This suggests that STC may have had no plan. Though the bottom welds may have been adequate, documented cases of bottom weld failure leading to tank collapse can be found in technical literature.

5.2.3.1, 5.2.3.2 Tank Shell Alignment—This section places limits on tank shell plate misalignment. Apparently, compliance was never verified. Skinner Tank believes that a tank can only be put up one way. This presumably eliminates any need to verify compliance with tolerances.

5.2.3.6 Inspection Of Shell Opening Welds—Welds which attach nozzles and other openings must be inspected. Generally, opening welds are to be inspected by liquid penetrant or magnetic particle methods. However, flush type openings have special requirements which may include 100% radiography. (See 3.7.8.11) Records show that nozzles were added to the shell during reassembly. However, there is no evidence that any inspection of these welds was performed during reassembly at Floreffe.

5.3.1.1 Purchaser's Inspector—The purchaser's inspector is to be allowed free access to the job site. A related section, 4.2.1., guarantees access to the manufacturer's shop. Ashland did not exercise this option. Project Engineer Walters visited the site perhaps four times during construction. Terminal Manager Morgan was present at the site and usually stopped at the job every day. However, neither man was acting as an inspector. Both lacked the expertise to do so. Morgan also lacked any authority to do so. There is no evidence that Ashland hired a contractor to inspect the job or requested help from the Ashland refinery inspections group.

Thus, Ashland failed to act affirmatively to ensure a quality product or compliance with the relevant standards. Ashland seemed to assume that STC and other contractors would do quality work and comply with the applicable standards on their own. This view left no role for Ashland to play. Such non-feasance at the project's conceptual level set the template for Ashland's disengagement from procedures at the operational level.

5.3.2.1 and 5.3.2.2 Visual Inspection of Welds—The purchaser's inspector is specifically

authorized to visually inspect welds. There is no evidence that Ashland did so.

5.3.2.3 Costs of Radiographs—The cost of radiographs is allocated to the manufacturer. STC did not pay for or arrange for the radiographs. Larry Skinner did not believe that API-650 requires radiographs, but agreed that the purchaser may choose to have radiographs taken. STC's work is generally not radiographed.

5.3.5 Reinforcement Plate Weld Testing—All reinforcement plate welds are required to be tested by applying pressure. A reinforcement plate is an additional plate added to strengthen the shell around an opening. The Task Force uncovered no evidence that any welds other than floor and shell welds were tested in any manner.

5.3.6 Hydro Test—This section requires that the tank shall be filled with water prior to being placed in service. This was not done. (See also 3.6.1.5) STC was responsible for compliance with this section. However, it does not believe that API-650 requires a hydrotest, and took no steps to perform one. Ashland stepped into the void, and assumed responsibility for the test from the start.

STC and Ross claimed that oil penetration, a so-called alternate testing method set forth in 5.3.6.2, was utilized. The Task Force has received conflicting evidence of whether this "alternate test" was actually done over the whole shell. Regardless, there is no alternative sanctioned under these circumstances by API-650. According to API, there is no alternative test. The hydrotest must be performed if water is available. API explained that unavailability means literal unavailability. Difficulty of obtaining water, or the length of time required to fill, are not justifications for dispensing with the hydrotest requirement. API formally responded to a question about the meaning of this section in its 1984-Technical Inquiries Publication. API wrote "[t]he 5.3.6(2) provisions are included to provide for oil tanks in remote locations, where water for testing is not at all available, or at locations where sufficient water to fill the tank is not available." (at p. 26.) Water was available.

5.3.7 Roof Weld Testing—This section requires that the roof welds be tested by applying a vacuum or air pressure. The Task Force has uncovered no evidence that welds other than floor and shell welds were tested at all.

5.4.1 Notification of Weld Defects—This section requires the manufacturer to inform the purchaser of all weld defects and obtain approval prior to repairing them. There is evidence that some defects were discovered during floor testing, and perhaps, shell erection. However, there is no evidence that Ashland was informed of the defects.

5.5 Dimensional Tolerances—This section specifies certain dimensional tolerances for tanks. The Task Force uncovered no evidence that compliance with these tolerances, like those of 5.2.3, was checked.

5.5.5 Foundation Level—Prior to the hydrotest, the foundation's level must be checked around the circumference of the tank. (5.5.6) Gateway Engineers, Inc. surveyed the elevation of the tank. Readings were taken at 13 locations around the tank's circumference, about every thirty feet. This showed the foundation to be true to plane. However, 5.5.5 requires the elevation to be checked at each ten feet of circumference.

6.1 Number of Radiographs—API-650 requires radiography of shell welds. This section specifies the number of radiographs required. The radiographer, Progress Services, was hired to take 40 radiographs of welds on Tank 1338. Ashland believed that this number of radiographs satisfied the requirements of API-650. However, Project Engineer Robert Walters was not sure which edition of API-650 he used to calculate the number of radiographs required. Per API-650, seventh edition, at least the following number of radiographs were required:

T-Joints (1st, 2nd, and 3rd Courses)	= 72
Vertical (Lowest Course)	= 24
Vertical (2nd, 3rd, and 4th Courses) (One in the first 10 feet and one in each 100 feet following for each plate and welder)	= 4
Vertical (5th, 6th Courses) (One in first 10 feet; one each 100 feet following for each plate and welder)	= 4
Horizontal (All) (One in first 10 feet and one in each 200 feet following for each plate size and welder.)	= 15
Total:	**119**

This is the minimum required since the formula, in part, is based on receiving radiographs of each welder's work. It is impossible to tell which welders or how many welders worked on the tank due to the lack of records or stamping. (See 7.3.3.1) Even if all 39 radiographs were shot on the lowest course, more radiographs would have been needed there.

6.1.2.7 Timing of Radiography—This section states that radiography should be done as soon as practicable. API suggested that this means that radiography should be done while the job is in progress. The radiography on Tank 1338 was done after the welding was complete. Progressive radiography, that is taking radiographs as work is completed, is preferable because it not only identifies defective welds but affords an opportunity to prevent more defective welds. This latter benefit can be achieved by educating the welder, firing the welder, or revising the welding procedure. The presence of a radiographer also motivates welders to do a good job. Radiography performed at the end of a job naturally leads to a difficult choice if many defects are found: whether to reject an otherwise acceptable tank.

6.1.6 Limits of Defective Welds—If radiographs locate defects, additional radiographs must be taken to determine the defect's limits. This was not done; only the originally requested radiographs were taken.

6.1.7 Repair and Reinspection of Defective Welds—This section states that all defective welds shall be chipped or melted out and reinspected. There is conflicting evidence that a few defective shell welds were repaired, but no suggestion that all were repaired. Progress Services did not return to do additional radiography; the Task Force has uncovered no evidence that another radiographer was hired. Thus, any welds repaired could not have been re-radiographed.

7.2 Welding Procedure Specification—This section requires that the manufacturer assure the suitability of its welding procedures, and maintain Welding Procedure Specifications (WPS) in accordance with Section IX of the ASME Code. In response to a Task Force request, STC produced no WPSs and later admitted that it had none. Former STC employees stated that they were not familiar with any written welding procedure. The WPS defines the parameters of a weld which, if made properly, will be a good joint. Variables to be stated include: material, thickness, weld material, welding process, and type of joint. Adherence to the WPS also assures uniformity of welds. This is important, because two unguided welder's welds will likely not be the same.

The validity of a WPS is documented with Welding Procedure Qualification Records (PQR). PQRs are records of specimen tests used to qualify a WPS. Numerous PQRs are needed to qualify one WPS, because each WPS typically contains many variables. Each essential variable must be checked in separate tests. Essential variables are those parameters which will affect the mechanical properties of the weld.

Three PQRs, dated 1981, 1983, and 1985, were produced pursuant to a Task Force request for welding documentation. The laboratory which tested each specimen assigned a number to it. These numbers show up again, in another document, on the line reserved for the actual Welding Procedure Specification number on STC's Welder Qualification forms. When completing these Welder Qualification forms, the manufacturer should identify the particular welding procedure that the welder was following when he took his qualification test. The incorrect use of the PQRs suggests that since Skinner Tank had no welding procedure, it attempted to rely on a few limited tests of welds. This is a flawed practice. A few discrete tests are no substitute for a WPS with numerous permutations. This conduct indicates either an attempt to evade the requirements of Section IX of the ASME Code or ignorance of those requirements.

Two of the PQRs from STC tested essentially identical groove welds; the third qualified fillet welds. The groove weld tests were for 3/8" thick, A-36 steel plates welded manually by the Shielded Metal Arc process (SMAW) in the 3-G (vertical) position. The 1985 PQR used an E6010 electrode; the 1983 PQRs tested both E6010 and E7018 electrodes. While the joints are Single-V, joint type is not an essential variable. At best, these PQRs limited Skinner Tank to SMAW groove welds of A-36 plates, no greater than 3/8" thick made with E6010 or E7018 electrodes. No welds on the shell of Tank 1338 meet these

specifications. Most plates were thicker than 3/8". The material analysis of NBS has shown that the steel was not type A-36.

7.3.1 Welder Qualifications—The manufacturer is required to test all welders and qualify them in accordance with Section IX of the ASME Code. Upon Task Force request, Skinner Tank produced copies of Welder Qualification Records (WQR) for welders who worked on Tank 1338.

The documents produced raise substantial questions. With the exception of one qualification record, all the tests were administered by STC personnel to their own welders. Outside consultants are sometimes used for these tests to avoid any question of conflict of interest. None of the WQRs qualified in-house by STC bears the signature of an individual who ostensibly tested the welding specimens prepared by the welder tested. The signature, if present, would certify the accuracy of the results. A space is specifically provided on the form for this. Interestingly, only the WQR tested at an outside laboratory is signed in this fashion. In addition, much of the information on the form, as well as Larry Skinner's signature purportedly certifying that the specimens were prepared in accordance with Section IX of the ASME Code, may be considered skeptically. Based on their appearance, these forms were submitted for analysis to the documents laboratory of the Pennsylvania State Police. The laboratory concluded that the "Skinner signatures contained thereon, and a considerable portion of the typewritten entries appearing thereon, were all prepared from the same source document." Translating this into the vernacular, the documents examiners found that the welders' qualifications records, including Larry Skinner's signature certifying the correctness of the reported results, were not individually prepared for each welder they should pertain to but instead were simply photocopies of each other (with generally the exception of the name) or some other source document.

There is insufficient evidence to conclude at this time that these records are fraudulent. It is possible that the same tests are always performed by welders and that Skinner personally reviewed the results before operating the photocopy button. Use of photocopied test results, however, is more troubling than just photocopied test descriptions. While an identified test may always be administered, the results presumably will vary from welder to welder and occasion to occasion. Thus, the documents on their face completely lack credibility and would not have served to inspire confidence in the qualifications of these welders.

7.3.3.1 Stamping Welds—The manufacturer is required to identify each welder's work by stamping or by maintaining records of welders employed on each joint. Task Force inspection of the tank has revealed no stamp marks, and no evidence of records of welders employed on each joint has been uncovered. This departure from API-650 coupled with the absence of progressive radiography made individual welders virtually unaccountable for the quality of their work. The only continuing check on a welder's daily work was the foreman's visual inspection. Given the foreman's inability to be at more than one place at one time and the inherent limitations of visual inspection, this is a pale substitute for weld stamps or other checks.

7.3.3.1 Qualification Records—Welder qualification records are available to the purchaser upon request. Ashland never exercised the option to look at these records.

8.1 Nameplate—This section requires that the manufacturer place a name plate on the completed tank. The nameplate contains the manufacturer and fabricator's names, the vital statistics of the tank, and the edition of API-650 to which it was built. STC did not put such a plate on Tank 1338. It is STC's practice not to put this plate on its tanks. The only plate Ashland can identify in relation to Tank 1338 appears to come from a smaller, older tank. The origin of this plate is unconfirmed, but Ashland claims that it is relevant to a manway from another tank which was relocated to Tank 1338. This anomaly introduces more uncertainty into the background of Tank 1338 and the standard to which it was originally built. (Figure 19 is a sample name plate.)

8.2 Certification of API-650 Tank—The manufacturer is required to provide the purchaser with a document certifying that the tank was built in accordance with API-650. STC did not provide this document to Ashland, and generally does not provide it to customers. Ashland did not ask for this certification either.

Moreover, Ashland and STC also failed to satisfy NFPA-30. Section 2-1 of NFPA-30 deals with such topics as tank location, venting, fire protection, piping, prevention of overfilling and prevention of ignition. Section 2-1 of NFPA-30 requires that storage tanks be built in accordance with API-650, UL-142 or another enumerated code. Detailed compliance with other provisions of NFPA-30 is beyond the scope of the Task Force's investigation. It will not be addressed further.

Finally, Ashland also failed to comply with the Allegheny County Fire Marshall's regulations. As discussed above, Ashland did not obtain a permit. It has sought and received permits from the Allegheny County Fire Marshall in the past. Permits were issued for other tanks at the Floreffe facility in 1966 and 1978.

The Allegheny County regulations require that tanks meet the requirements of API-650 or UL-142. As discussed above, Tank 1338 complied with neither. A site inspection by the Fire Marshall's office and documentation of testing are also permit requirements. Neither requirement was fulfilled.

I. Critique of Construction Practices

1) Introduction

The preceding sections present the results of the Task Force's investigation, including the history of Tank 1338, description of its disassembly, erection and use, analyses performed, collapse mechanisms, and degree of compliance with applicable standards and codes. From this information, the Task Force has identified practices which it believes show a pervasive pattern of neglect and lack of concern for the quality of the intended product. Some are directly and causally implicated in the collapse, others are more subtly or obliquely related. Tracking the Tank 1338 project chronologically, these specific practices will be identified and critiqued in the order they surfaced. Relevant industry practice, if ascertained from interviews with petroleum and tank companies, will also be included.

2) Decision process

The first step in the Tank 1338 project, like any other construction project, was the decision to proceed. Some two and one-half years later many of the details of the process that led to the decision to relocate WI-16 to Floreffe remain a mystery. As discussed earlier, the exact number of individuals involved, their identities and their exact roles will probably never be known. There are almost as many permutations of the decision group as individuals interviewed. Records show that a need developed for a replacement tank at Floreffe. Several options, including relocation of WI-16, were investigated, to some degree, and reported in a memo. The next extant document authorizes the project to proceed. No documentation on the intervening steps exists. The process was, to say the least, informal, and suggests such highly diffused responsibility that the ultimate choice was made as much by inertia of movement as cognitive process.

The factors which influenced the decision are unclear. The primary criteria seem have been: 1) the simultaneous needs to remove WI-16 from the Whiskey Island Terminal and replace old tank 1338 at Floreffe; 2) Walters' cost estimate; and 3) the Refinery Inspection Group's inspection report on WI-16. The relative importance of these factors is unknown. There is no evidence that any of the following other important factors were considered: equipment reliability, change in service use, tank material, compliance with current codes, standards and industry practices, or effort required to place the tank in service. Such factors affect the economics of relocating the tank. They were not, however, factors in Walters' estimate, which was merely based on oral bids from contractors, in the inspection, or ultimately in the decision. All tanks were apparently treated equally—as though differences in service life, maintenance, modifications required, and improvements in material did not exist. This lack of information effectively prevented Ashland from making a reasoned decision.

Failure to consider the material involved seems, from this vantage point, to have been a particularly glaring oversight. As discussed previously, steels manufactured in the era of Tank 1338 are widely known to exhibit low-toughness prop-

erties. Particularly in cold temperatures, this characteristic markedly increases the risk of brittle failure. Failure to consider the material is also linked to Ashland's dereliction in not considering the change in service awaiting WI-16. The tank was insulated and heated during at least some portion of its prior use at Whiskey Island; the complete service history is unknown. As 1338, however, it did not hold heated products and thus the steel was subject to the full brunt of winter. If the tank had been heated for its full service life at Whiskey Island, it may never before have been subjected to the critical conditions of low temperatures and stress that caused the brittle failure on January 2, 1988.

Ashland apparently had not avoided rebuilt tankage in the past. Old 1338 was itself rebuilt at Floreffe. Robert Cruickshank described the relocation of two small tanks. At the time of the collapse of Tank 1338, Skinner Tank Company was reassembling another tank for Ashland at its Midland, Pennsylvania, terminal. No Ashland employee interviewed expressed doubts or concerns about the concept of relocating tanks, only the result here. STC claims that it rebuilds a significant number of tanks each year and expressed no reservations about rebuilding tanks or the ultimate product. Skinner Tank did not investigate the tank's condition prior to bidding or accepting the job. However, the other tank companies interviewed were very unenthusiastic about the idea of rebuilding tanks. Those interviewed will inspect the tank and refuse the job if they are not satisfied with the tank's condition. One manufacturer will rebuild only its own tanks, generally, due to concerns about the uncertain quality and condition of unknown tanks.

Industry practice generally disfavors tank reconstruction because it is not an economically sound practice, not because rebuilt tanks are inherently unsafe. Some companies have formally or informally banned the use of rebuilt tanks; others would be very cautious. The "tangible" costs of employing a qualified crew to tear down, transport, re-erect the tank, and make the necessary modifications to the tank must be considered along with the "intangible" costs of reduced service life, uncertain integrity, possible maintenance problems, and the chronic need to upgrade old tanks before returning them to service. These factors, often reinforced by bad experiences, have made the industry as a whole wary about using rebuilt tankage. Furthermore, the industry does not believe that using rebuilt tanks is justified by time savings.

3) Selection of staff and contractors

After the decision to relocate the tank to Floreffe was made, the manpower needed to perform the task was identified. Responsibility for the project was passed to the Facilities Engineering Group; Walters was selected as project engineer. He, with apparently little assistance or guidance, selected contractors to work on various aspects of the project.

The investigation has revealed a persistent lack of commitment to and concern about Quality Assurance (QA) or contractor qualifications by Ashland. There is no evidence of any company QA procedures. Not only are the qualifications of key Ashland personnel and contractors participating in this project questionable or doubtful, but there is no evidence that Ashland ever checked or tried to check qualifications. Indeed, the whole corporate environment placed no discernible emphasis on determining or verifying ability to do a job competently. Quality Assurance operates on the assumption that good quality work can be fostered or guaranteed by establishing and enforcing requirements and procedures. It provides a quantifiable means to an unquantifiable end. QA forces allegedly qualified and knowledgeable people to produce credentials, and document and justify their actions. There is no evidence that Ashland had an effective, aggressive QA system in place. Steele and Stringer, long time employees, stated that they were not aware of any Ashland QA policy.

a) Ashland employees

Ashland employees were apparently not familiar with the codes, standards and other requirements applicable to above ground storage tanks. Walters admitted that he was not familiar with Section IX of the ASME Code, but said that he was familiar with API-650 and NFPA-30. However, he was unable to identify the edition of API-650 he used to calculate the number of radiographs required or recall any details about

his calculations. Ross also stated that he was familiar with API-650, having worked with it in the past. He stated that API-650 does not require a hydrotest, a clear misunderstanding. Ross later admitted that he was not familiar with the current edition of API-650 and relied on some unnamed individual's representations that no hydrotest was required. Walters and Stringer were not aware of Chapter N of Mechanical Specifications, Ashland's own design specifications for welded steel storage tanks in refineries. This is remarkable in view of the fact that Stringer was on the distribution list for the document. This unfamiliarity with the applicable standards suggests an explanation for Ashland's failure and lack of interest in holding Skinner Tank to the requirements of API-650.

The documentation of the project was also substantively and procedurally inadequate. Relying merely on the documents produced by Ashland at the Task Force's request, one would have a difficult time determining what the project was, let alone how it was done. The most detailed project description comes from the approximately 50 words in the contract with STC. That passage, quoted earlier, describes the job in the most cursory terms. It may summarize the project, but it hardly defines it.

Nonetheless, there is no more detailed Ashland document, no drawings, and little documentation even identifying certain contractors (*e.g.*, Progress Services, Gateway Engineers, Zimmerman Excavating), let alone describing their work. Virtually no calculation packages or reports justifying designs or decisions exist either. The documentation produced for the Task Force is totally silent on the adequacy of the tank design, foundation design, or welds, to name a few prominent examples. As discussed earlier, paperwork and documentation required by API-650, such as the data sheet and certificate of compliance, do not exist, and are not used by Ashland as a matter of course.

Neither Walters nor Stringer hold four year engineering degrees or Professional Engineers' licenses. Nevertheless, they are classified by Ashland as engineers. Most engineers in Facilities Engineering lack these credentials as well. This does not necessarily affect their ability to perform many aspects of a project engineer's job. However, when tough technical issues arise, such as whether to accept defective welds, a stronger technical background is required. If help on such matters was available at Ashland, there is no evidence that Walters utilized it before or after the Inspection Group refused to examine the radiographs.

Several Ashland employees have voiced the opinion that the welds should not have been accepted. In addition, Carl Becker of Progress Services stated to the Task Force that whether the defects were in the "old" welds or "new" welds, the joints were defective. Though not an expert in welding, Becker was aware of certain properties of welds. Specifically, he knew that existing welds may be affected by heating from cutting or re-welding, and cannot be counted on to be the same as they were before disassembly and re-erection. Progress Services was hired by Ashland purely to take radiographs. It was not involved in the decision to accept the tank with defective welds; the decision was solely Ashland's.

Industry practice more closely tracks the requirements of API-650 than APC did. Many companies' internal documents exceed it. Generally companies use the API-650 data sheet or a similar form to order tanks, review drawings from the manufacturer, inspect the manufacturer's work to some degree, and receive certification that the tank is built to API-650 upon completion. Typically these documents are kept on file. Generally, engineers employed in the industry are college educated, but are not necessarily Professional Engineers. In addition, central engineering is available for consultation on difficult problems. In some companies central engineering, a brain trust of experienced professionals, is a resource that the field staff and project managers are encouraged to utilize. In marked contrast to the divided Ashland atmosphere, the technical staff at other companies is encouraged and sometimes required to work together. In at least two companies, engineers from various departments work together to develop company-wide standards.

b) contractors

There is no evidence that any contractor involved in the Tank 1338 project was asked to produce documentation of its employee's

qualifications or references to verify the quality of its work. Ashland contractors are chosen from a "qualified bidders" list. Adequate insurance coverage was understood by APC employees to be the sole criteria for membership on this list. Walters assumed, and stated in interviews, that STC was a reputable firm and an expert in the field. However, he based that opinion upon a single encounter several years earlier and upon representations from the tank company. STC was the low bidder and got the job exclusively on that basis. Ashland never reviewed its employees' qualifications, knowledge of the applicable codes and standards, resumes, or plans for dismantling and erecting the tank. Nor is there evidence that STC's qualifications or work were reviewed by an outside company.

This faith does not seem to have been well placed. Skinner Tank Company does not require its welders to be familiar with API-650 or Section IX of the ASME Code. At least one ex-employee was completely ignorant of API-650 and a foreman admitted to only "fair" knowledge of it. As discussed above, STC's welding documentation does not satisfy Section IX of the ASME Code. It admitted to having no written welding procedures as required by API-650 and Section IX of the ASME Code.

STC simply relies upon the welders to make good welds through judgment. This practice leaves the reliability and quality of the welded joints to chance. In addition, welders who leave the company's employ and later return are not retested as required by Section IX. STC does not typically use the API Data Sheet, prepare drawings, or certify that a tank was built to API-650. It does not identify material, and did not know the type of steel used in Tank 1338. Skinner Tank Company does not believe that API-650 requires a hydrotest or radiography, or that API-650 applies to rebuilt tanks. The Task Force found no evidence that STC performed any calculations or otherwise determined that 1338 complied with API-650, Seventh Edition. Semantic quibbles about the express applicability of API-650 aside, these omissions and derelictions were also in flagrant disregard of a material term of the contract between Skinner Tank Company and Ashland which called for compliance with API-650.

Zimmerman Excavating was completely unfamiliar with API-650 when interviewed by the Task Force. However, it was apparently capable of constructing foundations and accurately followed the drawing supplied by Ashland. Progress Services was also unfamiliar with API-650. However, after arriving at Floreffe, Carl Becker looked at the radiography section of API-650, which states that non-destructive testing shall be performed in accordance with Section V, Article 2 of the ASME Code, and that acceptability of radiographs is governed by Section VIII, Division I, Paragraph UW-51(b) of the ASME Code. Becker is qualified in the techniques of that section, including radiography, and familiar with the acceptance criteria. Though Ashland had only hired Progress Services to take radiographs, Becker pursued the possibility that more shots were required but was rebuffed by Morgan. Nevertheless, Progress Services' work was not capable of being reviewed after its completion. Upon reviewing the radiographs, the Task Force discovered that identification numbers were missing from some exposures. This omission, coupled with the admitted lack of a sketch showing the radiograph locations, would make finding the actual X-ray locations an ardous task. Though there is no evidence that Ashland checked Solar Testing's qualifications, there is also no evidence that Solar Testing's personnel were not qualified to operate nuclear density and other compaction testing equipment.

A company contracting for a large project should review its contractor's qualifications before selection and inspect its work during the job. Conceivably, due to a philosophical bias, a company might emphasize one way of insuring quality over the other. Ensuring its contractors' qualifications and competence, however, is particularly critical here since Ashland chose not to inspect its contractors' work. Proper inspection could have identified poor contractors or workers. As discussed below, Ashland declined either to carefully select or closely supervise; it relied on the contractors to police themselves without determining if they could or would.

The industry practice is to deal with contractors which have proven their competence as well as their financial responsibility. In addition, welder qualifications are often requested and

welders are sometimes tested. Drawings from the manufacturer are generally reviewed by the company for compliance with API-650 and internal specifications. The tank companies interviewed maintain all documentation required by Section IX of the ASME Code and possess expertise in API-650.

4) Responsibility and authority

Prior to the beginning of the project the responsibility and authority of the various participants should have been discussed and understood to minimize confusion and wasted effort during the job. There is no evidence that these matters were consciously considered in the context of this project, nor does any relevant Ashland policy seem to exist. Indeed, piecing together an organizational chart was difficult. Many individuals interviewed by the Task Force did not seem to be familiar with their own organization's structure.

Project Engineer Robert Walters stated that he handled the day to day aspects of the project, but James Ross, manager of Trucks and Terminals, exercised ultimate responsibility for all decisions. To borrow an analogy, Trucks and Terminals was Facilities Engineering's "client" in Walters' view. Therefore, James Ross exercised the authority of the customer by deciding not to hydrotest the tank. Without concern about the apparent contradiction, and without denying that the hydrotest decision was his, Ross denies that he had authority to overrule the project engineer. With regard to accepting the welds, Ross in fact failed to overrule Walters' incorrect decision. Walters is certain that Stringer advised him to follow Ross' on the hydrotest. Stringer does not recall this encounter, but was aware that Walters was receiving direction from Trucks and Terminals. Stringer's manager, Henry "Tony" Raiche, however, stated that such a conflict should raise a warning; the project engineer should refer conflicts with the "client" to his supervisor. Trucks and Terminals, in Raiche's mind, does not have the ultimate authority regarding engineering issues. The Task Force uncovered no evidence of a formal policy or document apportioning or defining intra-Ashland authority or responsibility. The end result was apparent confusion among Ashland employees about authority to make decisions.

This confusion extended to contractors. Some contractors, like Zimmerman Excavating, Progress Services, Solar Testing and Gateway Engineers, dealt almost exclusively with George Morgan and considered him to be the Ashland authority figure. Skinner Tank Company knew that Walters was in charge of the project. Its understanding of Morgan's role is not clear.

Communication and reporting is a related issue that illustrates the point that those in authority here were ill-defined. Though one reports to a supervisor, other interested parties are often informed or advised of developments. The difference is one of degree and purpose. However, it is hard to discern here any consistent theme or practice by which supervisors and others were formally apprised of developments. The issue is further complicated because those titularly in authority were wont to perform any supervisory functions. There is also no evidence that regular or formal channels of communication were utilized on the project.

Walters received verbal reports from Charles DeFranco, George Morgan and Leonard Fritchman. There is also evidence that he may have spoken to Ralph Zimmerman, Carl Becker, and Larry Skinner. There is no evidence that the content and frequency of these conversations was uniform or complete. Morgan was allegedly aware of defects in the "old" welds, but there is no evidence that Walters was so informed. Similarly, DeFranco apparently did not see the need to burden Walters with many details concerning the crane collapse. Walters occasionally advised Ross of progress. The content and frequency of these reports appear to have been sporadic, even though Walters alleged that Ross possessed ultimate authority on the project. Only Stringer received regular reports. These reports, like those of other project engineers, were only presented orally at the weekly staff meeting. Yet, Stringer somehow remained oblivious of every critical decision point in the project. Stringer provided Raiche, his manager, with a report for the engineering group based on information from these meetings. Neither Stringer nor Walters was aware if these reports advised Stringer of weld, hydrotesting or other problems, or if Raiche, in turn, was informed. Raiche, himself, claims no knowledge of these matters. It is not clear if Ross also

received reports on the tank's progress from his own section, the Trucks and Terminals group.

This system seems to have created an uneven, inadequate, and undocumented level of knowledge among the Ashland employees. This is vividly reflected in the diverging statements of different employees ostensibly involved in the same events. Management was apparently so poorly informed that it could not possibly monitor the job or spot problems, even if it were disposed to do so. Yet, there is no evidence that anyone involved found the level of detail or frequency of communication to be unusual. This approach, relying on employees to work things out in their own way, mirrors Ashland's approach to monitoring or inspecting its contractors' work. As noted previously, employees, in some cases, lacked the abilities and support to do so. The lack of regular, detailed communications successfully kept problems hidden from management until they literally assumed disastrous proportions.

As discussed earlier, in other companies the project engineer is more directly and personally involved in the job and, therefore, better informed. He should, in turn, be able to provide better information to his superiors. In addition, project engineers are generally part of the business unit that also owns and operates the terminals. This organizational unity avoids the conflict between groups. At least one company gives a defined role to the terminal manager in such efforts. The respective responsibilities of the terminal manager and project engineer are set out in a document.

5) Design/evaluation work

The next step in the process should have been evaluation of the existing tank, and design work on new items. Such effort would be directed at assuring the integrity and serviceability of the tank. However, there is every indication that the possible inadequacy of the tank was ignored by Ashland and Skinner Tank Company. API-650 assigns this responsibility to the manufacturer, STC in this case.

One critical item completely overlooked was the material of which the tank was made. As discussed above, the materials available for use in storage tanks have improved dramatically. The material requirements of the relevant API standard have changed correspondingly. Yet neither STC nor Ashland identified the material of Tank 1338, or apparently even gave any thought to it. This information is significant for at least two reasons.

a) welding

The type of material must be known to properly weld it. API-650 and ASME Section XI specify the electrodes to be used with each material. In addition, material type is a required variable in Welding Procedure Specifications required by Section IX of the ASME Code. (QW-403) Without knowing the material, it is impossible to be certain that the material is being welded properly and thus if proper welding procedures are being used.

b) structural integrity

A material's properties must be known to evaluate or design a tank. As discussed above, many sections of API-650 directly relate to material properties.

Notch-toughness indicates a material's susceptibility to brittle failure; yield stress determines, in part, its load carrying ability. Given the age of the steel involved the possibility that it was a low toughness material was great. Identification of the forty year old steel should have been a high priority. Identification can be made by a mill certificate, a document from the original steel maker which describes the steel, its composition, and other properties. Despite the fact that no mill certificates for the steel were available, no testing or consideration of the steel's properties occurred. Knowledge of the steel's strength was required to check design stresses. Finally, the effect of service temperature on the material properties, particularly toughness, should have been considered. As previously mentioned, during at least some portion of its prior use the tank was insulated and heated. Protected from the elements, it experienced neither the thermal stresses nor toughness reduction caused by cold temperatures. Perhaps the tank had never been subjected to cold weather before, and on January 2, 1988, for the first time, all of the requirements for brittle fracture were present: low-toughness material,

stress, and presence of a flaw. There is no evidence that any of this was considered by Ashland or STC.

Corrosion rate, perhaps the single most significant design parameter, also should have been evaluated. This is particularly important since the service conditions of the tank were significantly altered. Corrosion rate depends on such factors as: material, characteristics of the soil, type of foundation, environmental conditions, and product stored. Furthermore, the record is completely void of any calculations for the design of new items such as the foundation or shell openings.

The Task Force's interviews revealed a consistent industry view that tank material should always be identified. Some companies accept mill certificates, but at least one sometimes requires testing in addition to a mill certificate.

6) Dismantling

The next step in the Tank 1338 project was the dismantling of WI-16. The detached, undirected approach which had already come to characterize the project continued during this effort.

At least two of the techniques used by Skinner Tank in dismantling are controversial. The first is the technique used to remove insulation from the shell plates. As discussed above, the majority of the foam insulation was removed by driving a small front end loader fitted with a blade, called a "Bobcat," over the plates. Some plates were reportedly flattened or damaged during this process. This could have had a number of deleterious effects on the reconstructed tank, including reassembly problems, inability to meet tolerances, introduction of additional residual stresses, and alteration of material properties. In addition, this procedure could have introduced surface defects or notches to the plates. Such defects could provide an initiation point for a brittle failure. Walters was aware of this procedure, but claimed to be unconcerned. There is no evidence that Walters inquired into the wisdom of this procedure.

More controversial, however, was Skinner Tank's disassembly method. WI-16 was cut down along the edge of the existing welds, leaving most of the "old weld" intact. Though some of the "old" weld may have been removed when the plates were prepared and cleaned for re-welding, much of it remained and ultimately became part of the new joints in reconstructed Tank 1338. However, these "old welds" were later found to contain extensive defects. Leonard Fritchman noticed at least two defects in "old weld" material of the "prepped" joints during reconstruction. One member of the erection crew stated that defects visible to the naked eye existed throughout the "old" weld, and that Fritchman and Morgan were both aware of these readily evident defects.

Ashland was unaware and unconcerned about the particular procedure utilized for dismantling the tank. Walters never considered reviewing the procedure. In interviews, other Ashland employees opined that "old welds" should be cut down the middle and removed.

The industry practice favors removing the whole weld. The quality of "old" welds is generally considered suspect and, in any case, cannot be controlled. The practice of leaving "old" weld material may introduce defects into the tank. Besides reducing the strength of the welded joint, such defects have provided the initation point for brittle fractures. (Ref. 4; Ref. 5)

Had the "old" weld here been removed all of the resulting welded joints would have been of better quality. More specifically, the initiating flaw might have been at least partially removed if the joint was cleaned and beveled for re- welding. The flaw, as discussed previously, was located in base metal immediately below the "old" horizontal weld. If the "old" weld had been removed, the surface of the base metal would have been more or less exposed. Joint preparation removes some of the plate's material and might have taken some of the defect with it. (Figure 20 illustrates this point.) Instead, the "old" weld effectively shielded the flaw.

Finally, a crane used to disassemble WI-16 fell over and hit a pile of plates. Reportedly, some of the plates were damaged, and were manually reformed with hammers. Walters claimed to have had no knowledge of any plate damage resulting from the crane collapse. STC was unconcerned about the problem. This failure to inquire or investigate is troubling to say the least. The accident could have introduced surface notches and

defects into the plates, which are potential fracture locations. The damage could also make reassembly more difficult, and through unbending, introduce plastic deformation which could slightly reduce toughness.

There is evidence that the plates did not receive proper care during transportation from Whiskey Island to Floreffe. Though Larry Skinner and some crew members insisted that blocks were used to maintain the sheets' curvature, other former employees stated that no such precautions were taken. Failure to properly transport plates can cause them to lose their shape, and make reassembly more difficult. Flattening and rebending can cause some amount of plastic deformation, which, in turn, reduces notch-toughness. The plates may also lose their curvature, making reassembly more difficult. It is common practice in the industry to carefully transport plates using wooden blocks or "cribbing" to prevent a loss of curvature.

This entire phase of the Tank 1338 project occurred with no inspection, to speak of, by Ashland. Project engineer Robert Walters never visited the job-site. His sole source of information on the product was periodic telephone calls from Whiskey Island Terminal Manager Charles DeFranco. He was apparently the only Ashland representative present. DeFranco's role however, was not that of an inspector, but an observer. There is no evidence of direct communication between Walters and STC. Nevertheless, the investigation suggests that relevant details were not relayed to Walters. No one from Ashland questioned STC about its dismantling procedures, how it cut welds, removed insulation, or about the details of the crane accident.

7) Foundation preparation

Aspects of the preparation of the new foundation, or base, for 1338 also strike familiar notes. Settlement failures which cause tank leaks are hardly unprecedented and thus the construction of the base should be regarded as a critical point. Nonetheless, Zimmerman Excavating was chosen without having previously prepared a tank foundation and without being examined closely about its ability to meet the instant requirements. Cruckshank, who presumbly should have performed calculations and prepared the drawing for the base, responded as though the project were a communicable disease.

At the terminal, things were no better. Walters relied upon Morgan for information but the latter lacked the expertise or apparent desire to report knowledgeably about what was occurring. Morgan claimed not to know any lifts had failed the density tests even though he was present for them. Further, Zimmerman somehow determined that he could forego having failed lifts retested. None of this information made its way to Walters, and Walters did not make his way to Floreffe during this stage.

8) Erection

After the plates arrived in Floreffe the erection phase of the project began. Despite the change in scenery, many of the problems described above continued to characterize the project.

In the erection phase, like the disassembly phase, Ashland failed to effectively inspect any aspect of the job. Terminal Manager George Morgan filled the same limited role DeFranco had at Whiskey Island. Morgan was aware of STC's presence on site and stopped at the job-site regularly, perhaps daily. However, he did not actively follow what was done and was not qualified to inspect the work. In any case he lacked authority to do more. Morgan did not provide reports to Walters on a formal or regular basis.

Walters visited the site about four times during the erection of the tank. However, he admitted that he was not qualified to inspect welding, and visited only to check on progress. Leonard Fritchman spoke with Walters on an informal, irregular basis. The precise content of these conversations is not known. Walters did not request that someone from the Inspections Group oversee the job. In fact, he claimed not to know if Ashland employed individuals with such expertise. There is no evidence that a contractor was hired to oversee the job.

Neither Walters nor his manager Stringer explained why other inspection help was not sought. Apparently, there is no Ashland policy on this issue; the level of inspection and use of inspectors is left to the project engineer's discre-

tion. The Refinery Inspections Group might have been able to help, but this is by no means certain. Steele stated that an inspector might or might not be supplied depending on the project. Ashland's system essentially left the contracters on their own to perform an adequate job.

Industry practice differs with regard to inspecting construction activities and those differences are most profound between refineries and marketing terminals. Refineries generally have larger engineering and technical support staffs than terminals. Therefore, the inspection and monitoring done during construction of refinery tanks is somewhat more exhaustive than that performed on marketing tanks. However, the companies that the Task Force surveyed generally provided more support to terminal tank construction than Ashland. Typically, central technical staff or refinery personnel are made available or subcontracters are hired just to inspect and monitor work.

STC, sometimes in concert with Ashland, engaged in other construction practices which at the very least raise questions. As previously mentioned, a welder stated that though defects in the existing welds were visible to the naked eye, STC's foreman ordered the crew to weld them anyway because the "old" welds were not STC's responsibility. The same welder claims that Morgan was aware of the situation and approved of it. For reasons developed more fully elsewhere, this was a poor practice. Larry Skinner claims that the plates were cleaned and beveled to make proper double-V groove welds. A member of the erection crew disputed this and stated in an interview that edges were cleaned, but not beveled. The Task Force visited another Skinner Tank erection job which was suspended after the collapse of Tank 1338. The plate edges observed on that job were not properly beveled and prepared. API-650, ASME Section IX and sound welding practice all require proper joint preparation; improper preparation imperils weld quality.

In the course of constructing the tank, Larry Skinner and others stated that the tank was discovered to be not completely level. This was remedied by lifting the side of the tank with a crane and shifting some of the gravel under the tank. This may result in low spots under the tank and add additional stress to welded floor seams.

Finally, STC installed two water traps by excavating a portion of the foundation. Interviews and post-collapse observations showed that the excavated area was not recompacted. Potentially, this could create an unsupported region near the floor-to-shell connections—a critical connection where past failures have originated.

9) Testing

Testing of Tank 1338 should have been conducted progressively as the construction proceeded. It did not, and the testing that occurred was wholy unsatisfactory. Clearly, the basic requirements of API-650 were not satisfied. The two most significant ommissions in this regard were the hydrotest and the radiography. In addition, there is some evidence that even the diesel penetration test, the "so-called" alternative to the hydrotest, was not performed as advertised. Even if it was performed, it does not excuse the failure of both Ashland and STC to satisfy the requirements of API-650.

a) radiography

As discussed above, the number and kind of radiographs taken of 1338 was woefully inadequate, and even those actually taken were ignored. Thus Ashland was deprived of two benefits that it might have realized from radiography: flaw detection and determination of weld quality.

There was no radiograph taken at the location of the originating flaw. It was located near a T-Joint, between the first and second course. It would have been radiographed if API-650, Seventh Edition had been followed. The standard requires radiography of all "T-welds" of plates of 3/8" thickness and greater. Based on Battelle's analysis of the flaw's origin, size, and geometry, it would have likely been seen in a radiograph. Thus, if Ashland had taken the number of radiographs required by API-650, carefully reviewed them, and acted on the unacceptable welds, the collapse should have been averted. The radiograph inspection is not a requirement without a purpose or benefit. Welds hold the tank together; they turn a pile of steel into a structure. Thus, their integrity is critical. In addition, weld flaws have been documented as the initating point for other brittle failures. (Ref. 4)

The significance of this failure on Ashland's part simply cannot be exaggerated. Adherence to this mandatory, straightforward API-650 requirement for "T" weld radiographs should have revealed the flaw to the X-ray examiners and allowed it to have been corrected. Based upon Progress Service's fee schedule, this costly disaster could have been averted by an additional $50.00 X-ray. Moreover, APC's lack of concern for the prior experience of its contractors exacted a high toll here. Although there is no basis to criticize Becker's competence, he was not familiar with tank X-ray protocols or API-650 and consequently accepted the limited scope of his assignment with only mild resistance. A contractor more conversant with the industry standard may very well have been more vigorous in pointing out the obvious inadequacy of only 40 shots.

The radiographs that were taken showed poor weld quality, with gross porosity, lack of penetration, undercutting, and lack of fusion defects in both "old" and "new" welds. Ashland was aware of this but chose to accept the tank on the assumption that all defects were in the "old welds." Since those welds had served adequately for many years, Walters assumed that there was no reason to doubt their integrity or servicability now.

The assessment that all defects were in the old weld was provided by the radiographer, not a welding expert. The Task Force and NBS have concluded that defects existed in both "old welds" and "new welds." Additional radiography would have likely revealed more of the same. Worse yet, the decision to accept the tank with the defects was made by Walters, who professes no welding expertise. Proper attention to the radiographs by qualified individuals would have provided ample reason to reject Tank 1338. This rationale is based solely on defective welding, and is independent of the existence of a flaw or mere code compliance. Ashland employees, including Stringer, Raiche and McCoy, stated that qualified radiographers are employed in the Refinery Inspections Group, and these individuals could have provided assistance to Walters. However, Walters' only asserted attempt to get help interpreting he radiographs proved futile. He then substituted his own judgement.

Walters judgement was as flawed as the welds. After repeated heating through welding and cutting, welds cannot be expected to exhibit the same properties, which makes reliance upon their prior service invalid. Furthermore, neither API-650 nor ASME Section IX recognizes the "new" weld - "old" weld distinction. If a weld is rejectable, it is to be rejected regardless of the defect's exact location. Finally, the large number of rejectable welds should have been a warning signal that the tank required serious re-examination and review prior to acceptance. Additional radiography would have likely revealed more of the same poor welds. Indeed, NBS took additional radiographs which showed poor quality in both "old" and "new" welds. The absence of identification numbers on some radiographs, and lack of a drawing showing the radiograph locations, would have greatly hindered any attempt to re-inspect or repair the rejected welds. Leonard Fritchman and Larry Skinner both claim to have offered to repair the rejected welds, but were told by Ashland that no repairs were required. However, a member of the welding crew at Floreffe stated that Fritchman took the position that STC was not responsible for defects in the "old" welds. He held this view during the erection and expressed it on the very day that radiographs were taken.

In addition, had radiography been performed as work progressed, remedial steps including education of welders, replacement of personnel or contractor, or revising the welding procedure could have been taken. Others experienced in tank construction noted that the open and recurring appearance of the radiographers also serves to motivate lazy or sloppy but qualified welders to do the kind of work of which they are capable. Conversely, delaying radiography to the completion of the project virtually encourages negligent workmanship. By waiting until the job was complete before taking radiographs, Ashland's only options were to accept or reject the whole tank. Given the number of defective welds, repair was probably not a viable alternative. APC had essentially lost control over weld quality. Ashland exposed itself to this risk by not verifying welder qualifications.

Radiography is routine industry practice. Some companies' in-house procedures require

radiography in excess of API-650 requirements. Some tank companies have in-house radiography capabilities, others arrange with contractors to do the work. It is not uncommon, however, for the customer to take responsibility for radiography. Individuals knowledgeable in radiography are generally on site during the radiography and review the film on the purchaser's behalf.

b) hydrostatic test

The hydrostatic test, or proof test, was also neglected. It involves filling the tank with water prior to placing it into service. The hydrotesting requirement is not new and can, in fact, be found in the predecessor to API-650, API-12C. A hydrotest is required not only by API-650 but by Chapter N of Mechanical Specifications, APC's internal procedure. At best, an extremely limited hydrostatic test was performed on Tank 1338.

There are four reasons for performing the hydrotest: i) strength check, ii) leak check, iii) foundation check, iv) fracture check and prevention. The value of each of these functions was compromised by the test which was done.

i) strength check—

Most basically, filling the tank tests the strength of the structure. Since most petroleum products are lighter than water, the hydrotest is designed to test the tank's integrity by placing a greater load on the tank than it will see in service and thereby providing a "safety margin." Ashland considered a 3.4 million gallon hydrotest, which, if it had been conducted, would have defeated the conservative underpinnings of the procedure. Battelle, NBS and the Task Force have concluded that the collapse of Tank 1338 was not caused by a strength failure. However, failures have occurred during hydrotest, and have been documented. (Ref. 1 at 762; Ref. 3 at 143) Nevertheless, it is not likely that a hydrotest would have overstressed Tank 1338 and caused it to collapse. NBS calculated the maximum shell stress due to a capacity load of product to be 15.0 ksi. Since water is about 15% heavier than No. 2 fuel oil a maximum stress of 17.25 ksi would result from a hydrotest. This is lower than the yield stress and strength of the steel as determined by Battelle and NBS.

However, a hydrotest still might have initiated a leak. The hydrostatic "head" also causes crack growth. This is not a strength failure and will be discussed below.

ii) leak check—

The hydrotest also checks for cracks in welds or base metal. Since the water is driven by significant "head", it will reveal cracks that the diesel penetration test assertedly performed by Skinner Tank might miss. The diesel fuel used in the latter test is simply sprayed on a plate's surface, and has no pressure behind it. The hydrotest may also cause smaller cracks to grow. If growth extends through the shell's thickness, and conditions for brittle fractures are not present, a leak will result. Admittedly, the hydrotest can only detect weld defects which extend throught the full thickness of the joint, or grow to that size during the test. Radiography or ultrasonic testing, which also detect other flaws, are better indicators of weld quality, but are not taken in all locations. Hydrotesting checks all the welds, and could reveal detective welds where no radiographs were taken. The initiating flaw did not extend through the shell of the tank until the collapse occurred and, probably would not have been revealed by it. However, the test may have revealed leaks in other locations. Due to the short service life of Tank 1338 at Floreffe and questionable in- service inspection practices, it is impossible to determine whether it would have leaked.

iii) foundation check—

Loading a tank allows it to become seated on the rock foundation. This is one of the reasons that James Ross ordered some water placed in the tank in June, 1987. Full hydrotest loading may reveal a potential settlement problem. There are documented cases in which the hydrotest has revealed a foundation problem. (Ref. 1 at 764) The Task Force, Battelle and NBS have concluded that the foundation was sound and a hydrotest would likely not have revealed a problem. However, given the foundation's unknown — and unknowable — design and construction process, Ashland should not have been so confident. This perhaps explains why settlement was checked again after the water was drained and just over ten feet of product was placed in the tank.

iv) fracture check and prevention—

The Task Force, Battelle, and NBS agree that the collapse of Tank 1338 was caused by a brittle fracture. However, it is unlikely that a warm weather hydrotest would have caused brittle fracture. Static brittle fracture requires three conditions: a low-toughness material, a crack or flaw, and some amount of stress. The hydrotest can only contribute stress. As discussed earlier, technical analyses have assumed that the area of the flaw was at yield stress due to applied stress plus residual stresses. Since yield stress is, for all practical purposes, the maximum stress, the hydrotest could not enhance the stress level. This stress would have been insufficient to cause a failure during warm weather, when the steel was relatively tough. Brittle failure is most probable during cold weather when steel is least tough. Temperature can affect steel toughness significantly; for reasons of convenience, hydrotesting is generally done in warm weather. (Ref 1, 2, 3, 5) If conditions are right, however, a brittle fracture could occur during a hydrotest, perhaps if significant crack growth occurred, for example.

While a warm-weather hydrotest may not cause or reveal a potential a brittle failure, it may prevent failure by "crack blunting," or crack arrest. This phenomenon causes an existing crack or notch (Fig. 21(a)) to stop growing. The hydrostatic "head" of the water causes the crack to separate and grow. The tip of the crack is placed in tension, and plastically deformed. (Fig. 21(b)) After the water is removed the crack closes placing the tip in a state of residual compression.(Fig. 21(c)) The sharp tip has been "blunted." The crack will not grow until the residual compression is overcome and the tip is again placed in tension. Crack blunting is a documented procedure and can prevent a crack from growing.

The effects of "crack blunting", however, are almost impossible to quantify. Indeed, if the crack growth was great enough a leak or brittle fracture would result rather than arrest of the crack. In some ways the procedure is analogous to a vaccine. A vaccine immunizes most people, makes some sick, and kills a few. The flaw in Tank 1338 apparently grew. However, the mechanism and time of crack growth cannot be determined, nor can the success that a hydrotest would have had in retarding that growth.

Industry practice overwhelmingly favors complete hydrotesting of tanks. All of the major petroleum companies interviewed by the Task Force require hydrotesting of new and repaired tanks. Many have also written a hydrotesting requirement into their in-house design document. In addition, the tank construction companies interviewed by the Task Force consider hydrotesting standard practice. Fisher Tank, in fact, requires a written waiver from any customer who refuses to allow a hydrotest to be performed. API, of course, believes that a hydrotest is required by the terms of API-650.

10) In-service inspection

Though not in service long, Tank 1338 was involved in Ashland's In-Service Inspection program. The need for inspection does not end when the tank is placed into service. Like any piece of equipment, a tank has an undetermined but finite service life. The service life depends on many factors: material, location, maintenance, product stored, and environment. Thus continuing inspection is required to keep a tank in good operating condition.

In-service inspection also may play a role in preventing brittle fractures. If a fracture mechanics approach is utilized, tanks may be designed to leak before fracturing by designing for a flaw the size of a leak. The leak, therefore, provides "warning" that the tank may fail. However, if the tank is not effectively monitored for leaks the benefits of this design are totally lost.

The responsibilities of the Facilities Engineering Section within APC are limited to construction and end when the tank is ready to go into service. Facilities Engineering is not responsible for in-service inspection of storage tanks and is not familiar with any in-service inspection policy. In-service inspection is the responsibility of Trucks and Terminals and is primarily carried out at the district or terminal level.

Ross outlined his understanding of the Ashland in-service inspection program. Daily "walk-through" inspections are conducted by terminal personnel. These inspections are limited to looking for leaks and gross indications of problems (*e.g.*, noises). Nothing is recorded unless "problems" are detected. Annually, the terminal

manager and district manager perform a more detailed visual inspection of each tank. The requirements of the inspection are set forth in a standard form. This form is passed on to engineering; the Inspection Group is only contacted if repairs are being made. Recently, Ashland has hired a contractor to perform acoustic emissions testing on its tanks. This procedure detects leaks with sound.

Morgan, in conflict with Ross' explanation, sought to place the responsibility for the annual inspection of the Floreffe facility on his District Manager, Paul McIntosh, but admitted that he and his operators actually perform the inspection. Technical people are not involved. Items checked include roof, vents, paint, and mechanical equipment. Reports are filed in the terminal. The daily inspections are performed by the operator assigned to the morning shift.

The Task Force has received no indication of when, if ever, tanks are taken out of service and a more thorough inspection performed. There is no evidence that Ashland has any internal procedures concerning repairs to tanks.

There is evidence, however, which challenges the efficacy and seriousness of the daily inspection. The inspection component of this daily chore is secondary to the primary purpose—collection of product data. Operators stated that they conducted no daily inspection *per se,* but they might notice something as they passed. All stated that the work is done early in the morning, at approximately 6:00 AM. Much of the year it is dark, and hard or impossible to see leaks or other indications of problems at that early hour. One operator stated that he often cannot perform the morning inspection without assistance of a flashlight due to darkness.

Though there are some differences, the industry practice regarding in-service inspection of tanks is relatively consonant with APC's. Like the construction process, there is a difference between refineries and marketing terminals. Refinery in-service inspection procedures are generally more exhaustive. Though due in part to their greater technical resources, refineries' in-service inspection needs are more critical since the tanks are larger and products generally more corrosive.

At other companies, terminal operators also perform a daily inspection while walking through the facility. This inspection is typically informal and involves looking for leaks and being alert for anything unusual that might indicate a problem. Industry practice and Ashland's procedures diverge somewhat on the matter of less frequent inspections. An annual inspection is also generally performed. This is more intensive, structured effort than the daily inspection. The terminal personnel are often accompanied by an engineer or inspector. The operation of pumps, gauges, vents and other equipment is checked on these inspections. Some companies also ultrasonically check shell thickness Approximately every ten years, tanks are taken out of service, cleaned and exhaustively inspected, inside and out. The procedures outlined above are consistent with the guide for "Inspection of Refinery Equipment," Chapter XVI - Atmospheric and Low-Pressure Storage Tanks, published by API. At least one company has an internal specification which sets forth the proper way to perform repairs on tanks Poor repairs have contributed to tank failures in the past. (Ref. 2, 5)

11) Summary

The preceding milestones on the Tank 1338 project are joined by a common road. At each step along the way Ashland as an entity failed to take any active or effective role in controlling its contractors or establish any procedures which might lead to a quality job. It was a passive consumer of the worst kind — apathetic as to potential problems, ignorant of actual events, unwilling to take any engaged role. Its employees were both institutionally and often personally unable to respond in any other way. Both the details and big picture equally escaped Ashland's attention. Compared against the applicable standards, its industry peers, or even common sense, Ashland's conduct and procedures can only be considered grossly negligent. The structural collapse at Floreffe can be directly traced to the supervisory bankruptcy at Ashland.

REFERENCES

1) J. Clarke, Recent Tank Bottom and Foundation Problems (Rcvd from API)

2) J. Fraylick, Inspection Program Cuts Tank-Failure Risk, Oil and Gas Journal, July 21 1986

3) C. Sammans, Results Of The Survey Of The Study Group On Oil Storage Tank Failures, Paper presented to API Convention, Houston, TX, May 11, 1954

4) G. Gurfinkel, Large Steel Tanks: Brittle Facture and Repair, Journal of Performance Of Constructed Facilities, Vol. 2, No. 1, pg. 30, February, 1988

5) I. LeMay, Metallurgical Investigation Of Failure Of A Large Crude Oil Storage Tank, Microstructural Science, Vol 10, P. 195, 1982

6) F. Hamel, An Investigation Of The Impact Properties Of Vessel Steels (A Progress Report), Paper Presented to an API Conference, May 13, 1958

7) R. Bell, J. Iwakirl, Settlement Comparison Used In Tank Failure Study, Journal Of Geotechnical Engineering Division, February, 1980, p. 152.

8) R. Darragh, Controlled Water Tests To Pre-Load Foundations, Journal Of Soil Mechanics and Foundations Divsion, September, 1964, p. 304.

9) W. Marr, J. Ramos, T. Lambe, Criteria For Settlement Of Tanks, Journal Of The Geotechnical Engineering Division, A.S.C.E., Vol. 108, No. GT8, August, 1982, pp. 1017- 1039.

10) Safety Digest Of Lessons Learned, Section 6, Safe Operation of Storage Facilities, Publication 758, Section 6, API, 1982.

11) J. Duncan, T. D'Orazio, Stability of Steel Oil Storage Tanks, Journal of Geotechnical Engineering, A.S.C.E., Vol. 110, No. 9, September, 1984, pp. 1219.

12) J. Duncan, T. D'Orazio, Differential Settlements in Steel Tanks, Journal of Geotechnical Engineering, A.S.C.E., Vol. 113, No. 9, September, 1987, pp. 967.

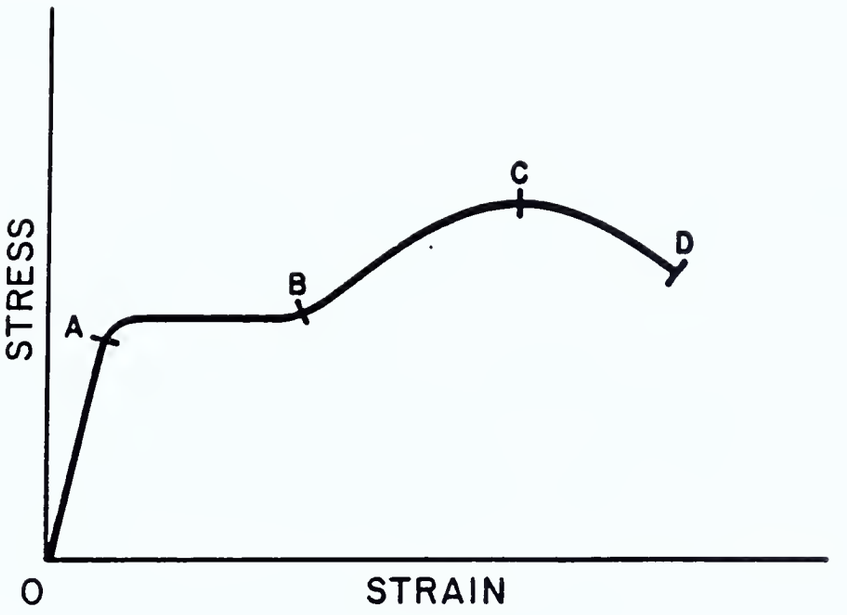


Fig. 6 - Stress Strain Diagram.

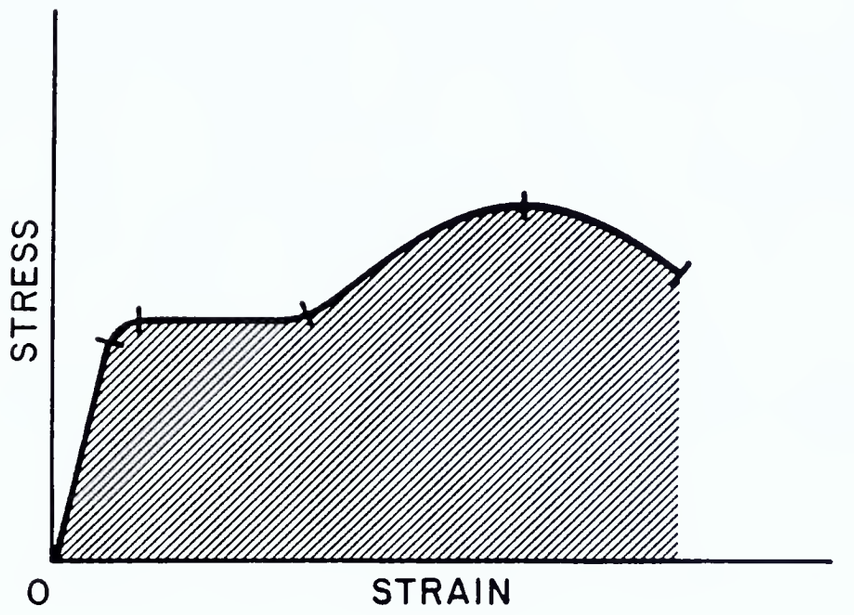


Fig. 7 - Stress strain diagram. Toughness is represented by the crosshatched area under the curve.

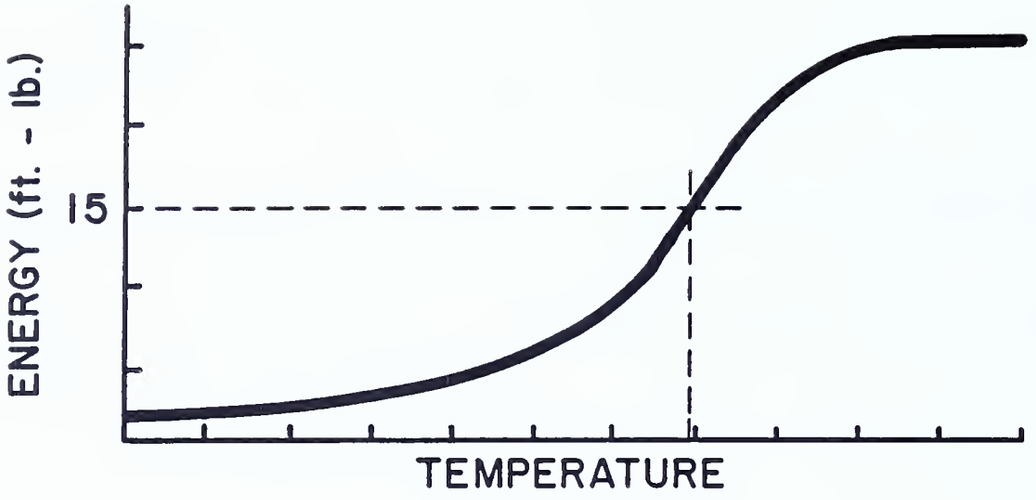


Fig. 8 - Transition Temperature Curve.

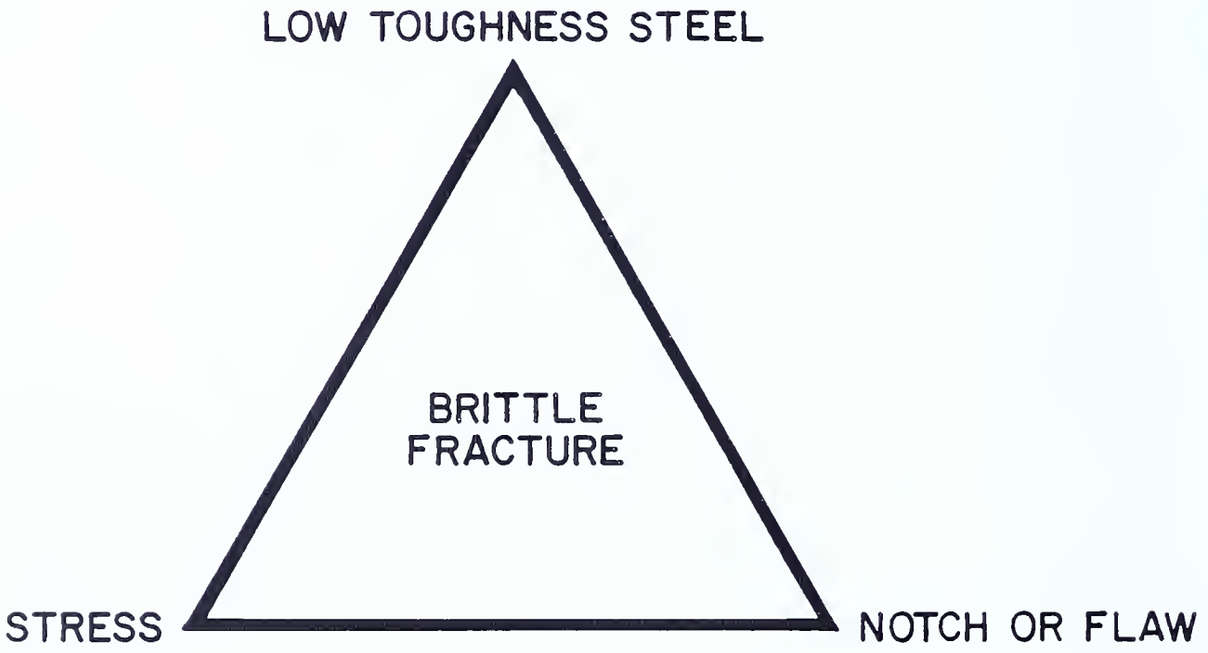


Fig. 9 - Factors affecting brittle fracture.

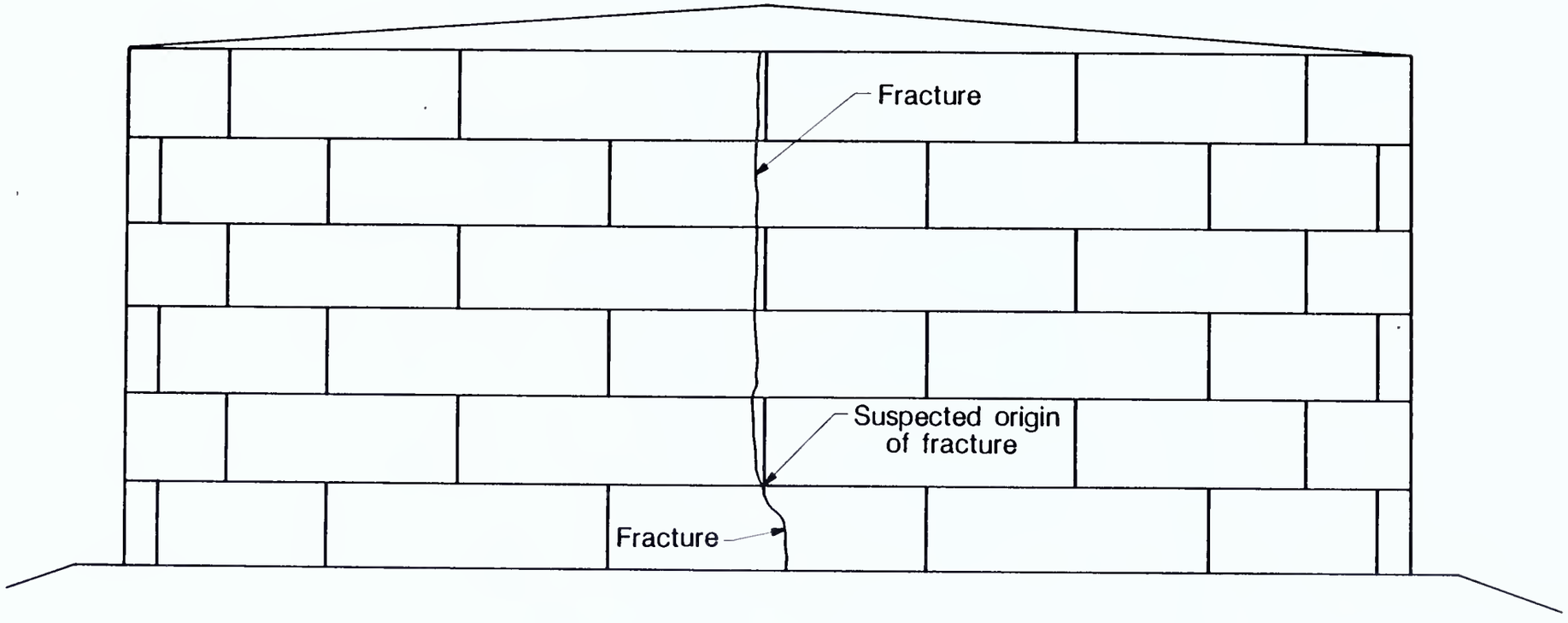


Fig. 10 - Sketch of tank 1338, looking northwest showing the fracture path. (Courtesy of National Bureau of Standards)

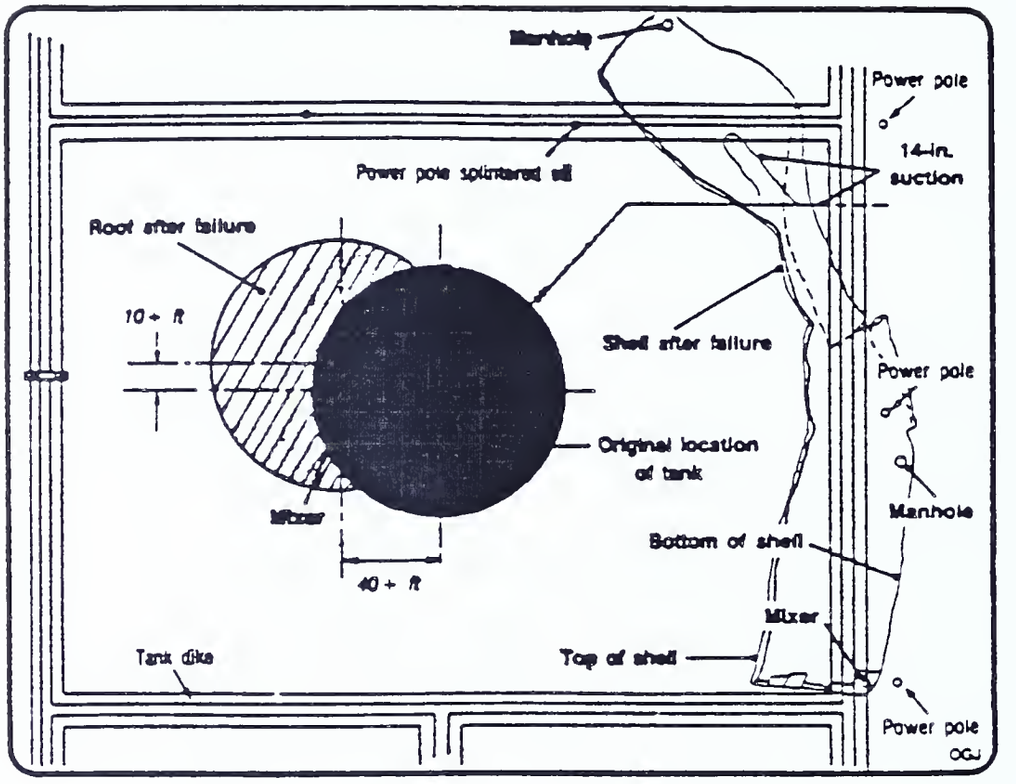


Fig. 11 - Sketch of 1972 collapse. Note the startling similarity to the Floreffe collapse. (Courtesy of John R. Fraylick, B. P. - America)

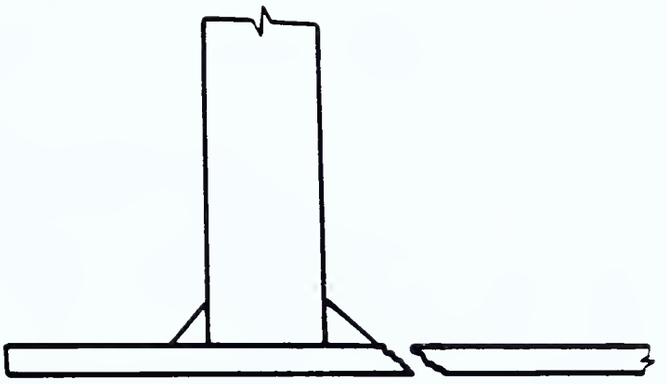


Fig. 12 - Idealized view of the floor fracture examined in the ductile fractographic analysis.

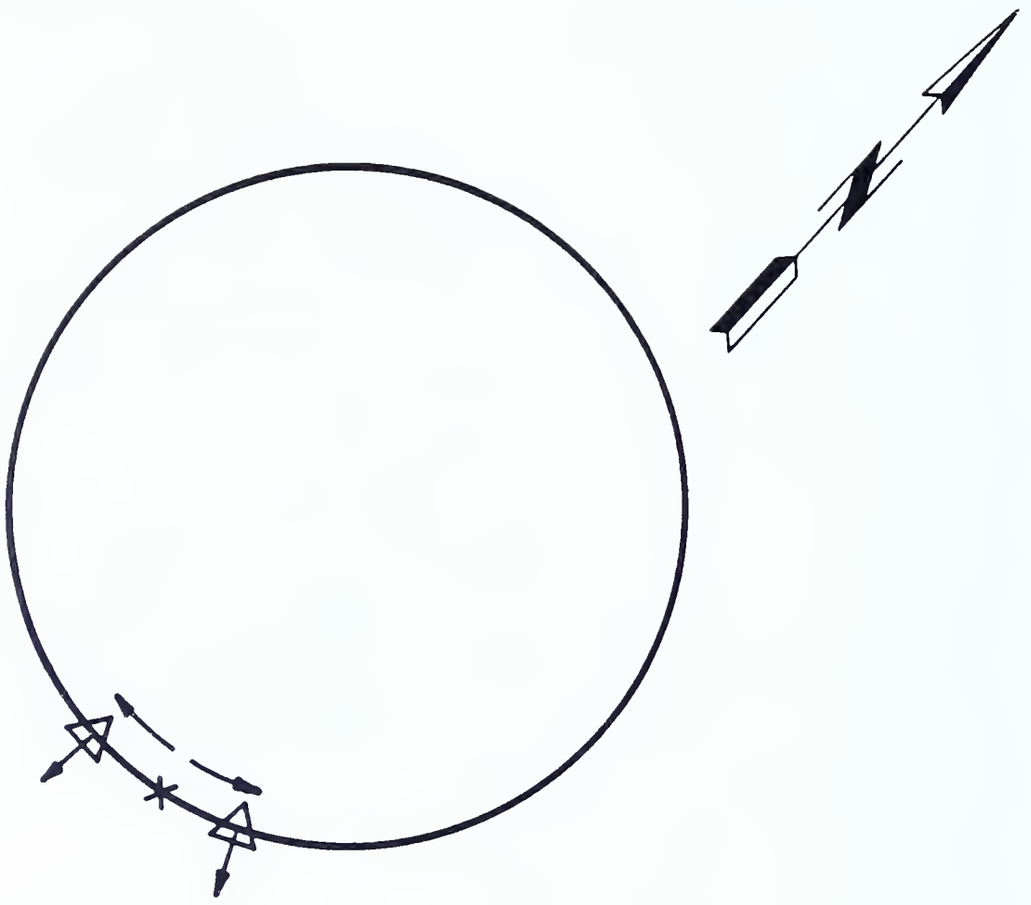


Fig. 13 - Idealized view of tank 1338. X is the location of the fracture. Sample locations are identified by △ . The small arrows next to each sample show the direction of the floor-shell separation as determined by the ductile fractographic analysis. Arrows at the X show the presumed direction of the separation.

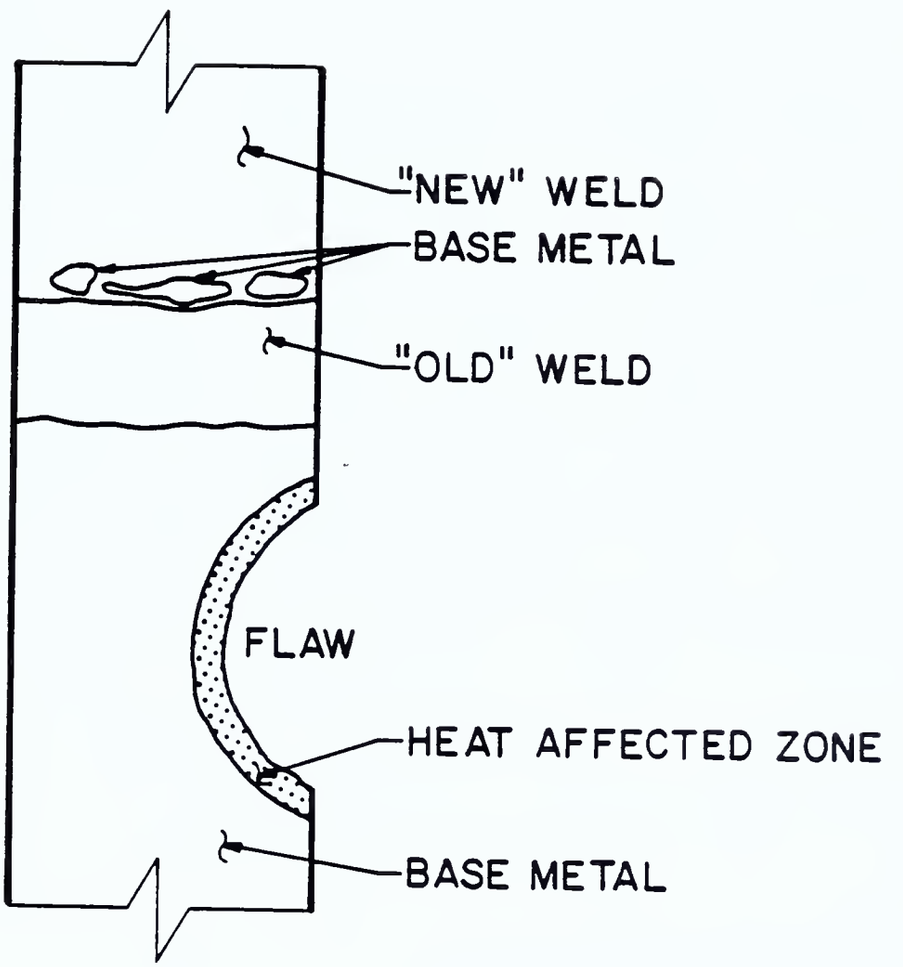


Fig. 14 - Idealized and enlarged view of the area surrounding the flaw.

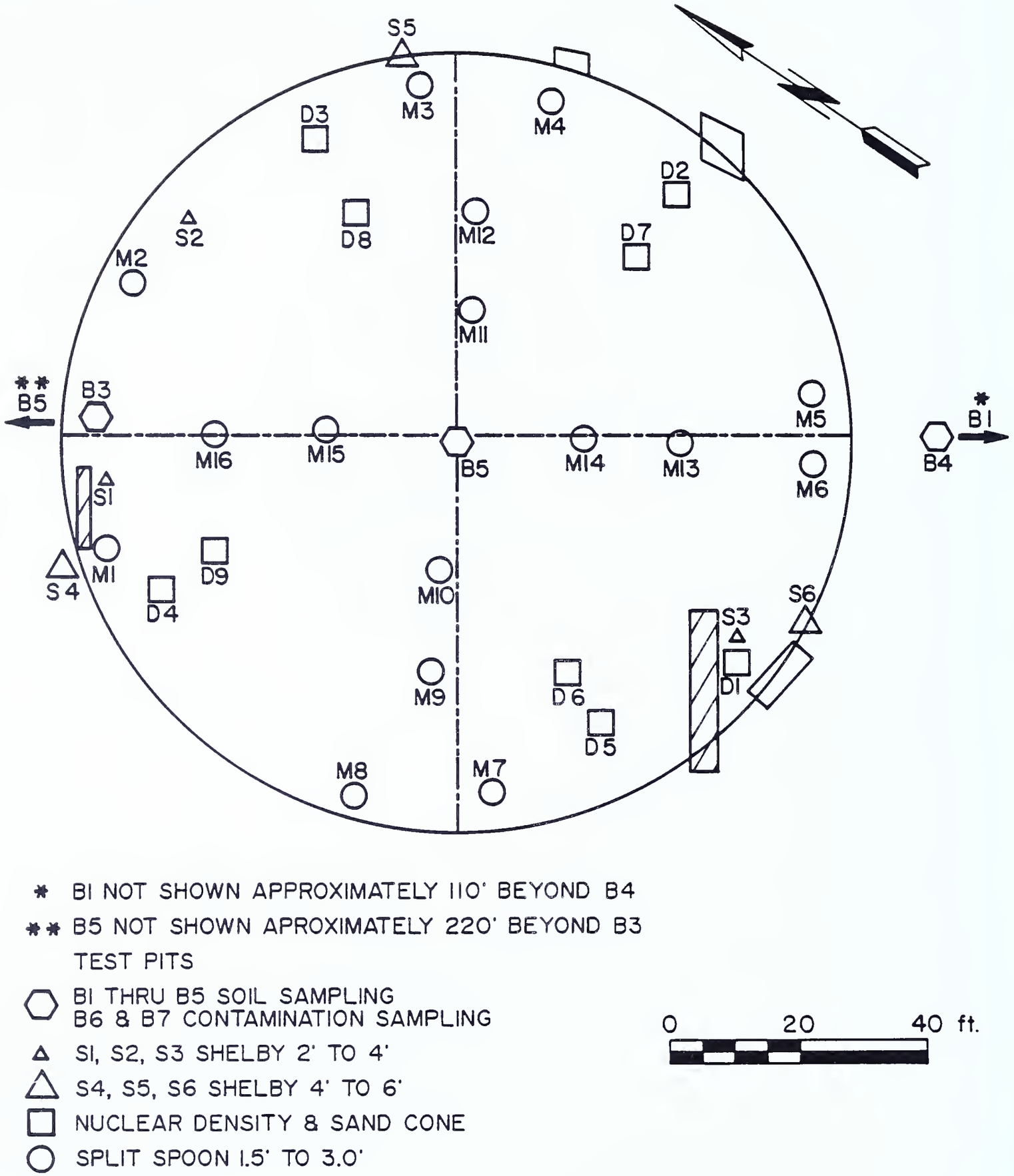


Fig. 15 - Sketch of tank foundation showing sampling and testing locations for task force geotechnical investigation.

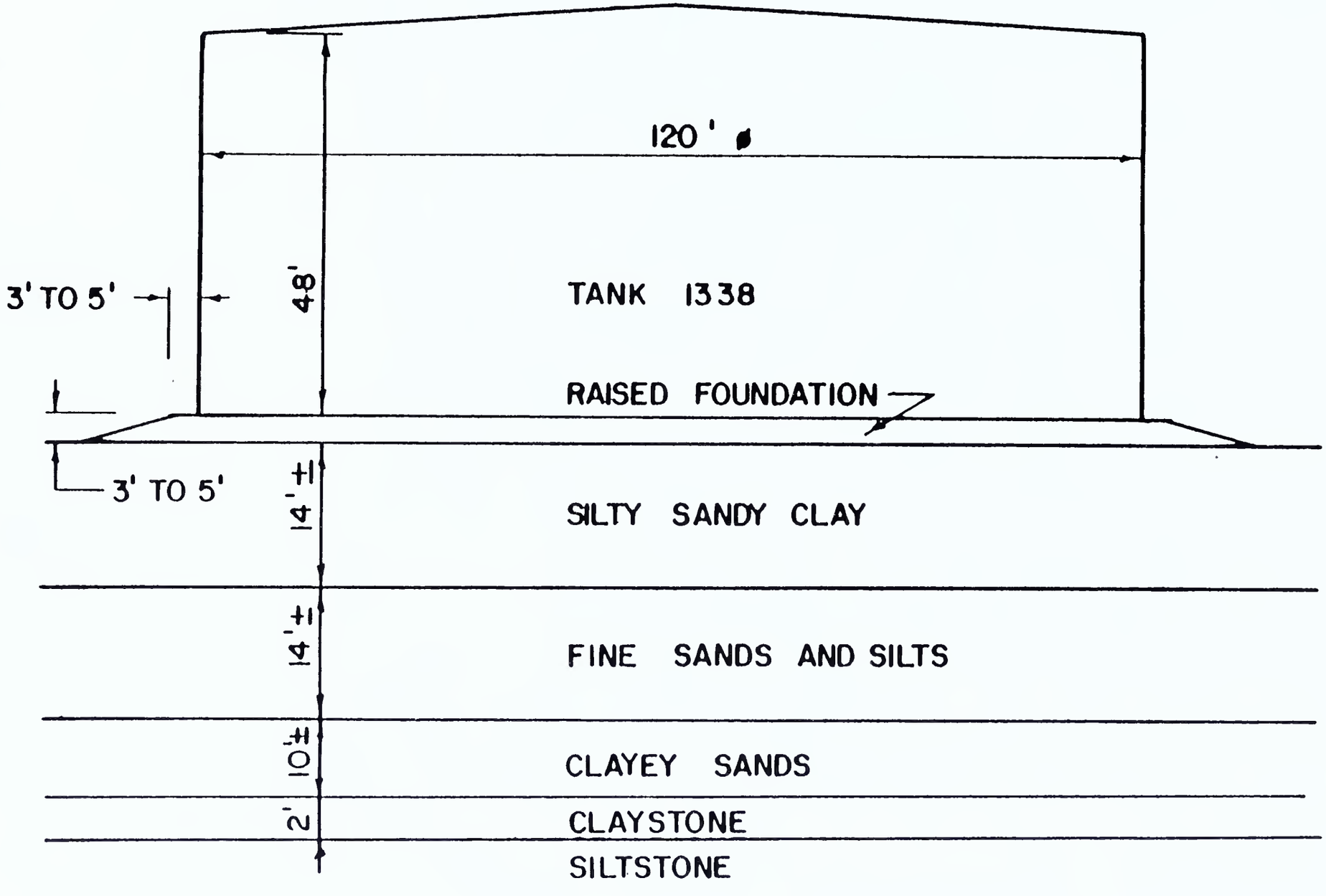


Fig. 16 - Cross sectional view showing sub-surface conditions.

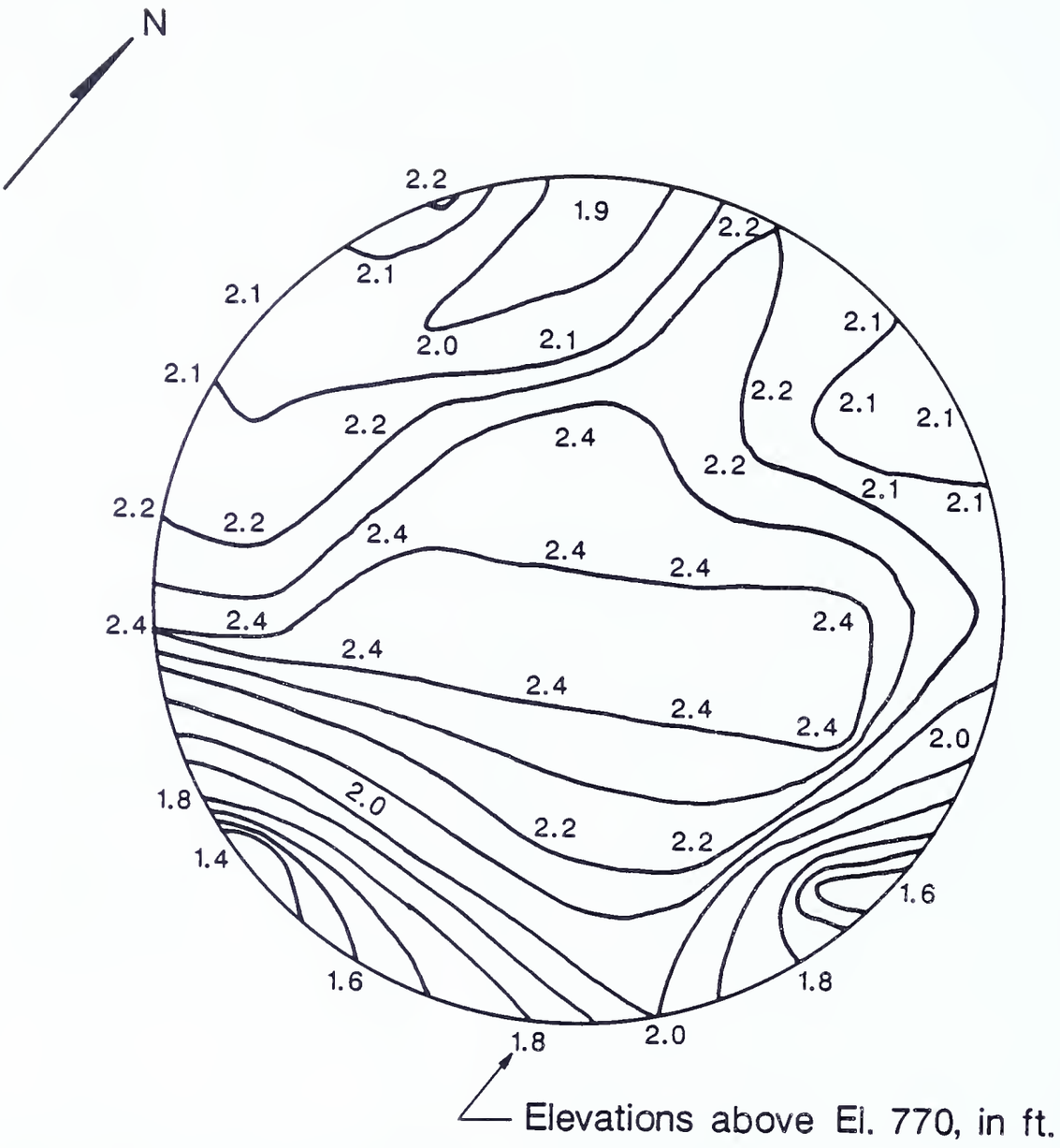


Fig. 17 - Surface elevations of tank foundation after failure and after metal base plate was removed. (Actual elevation equal 770 feet plus those shown)

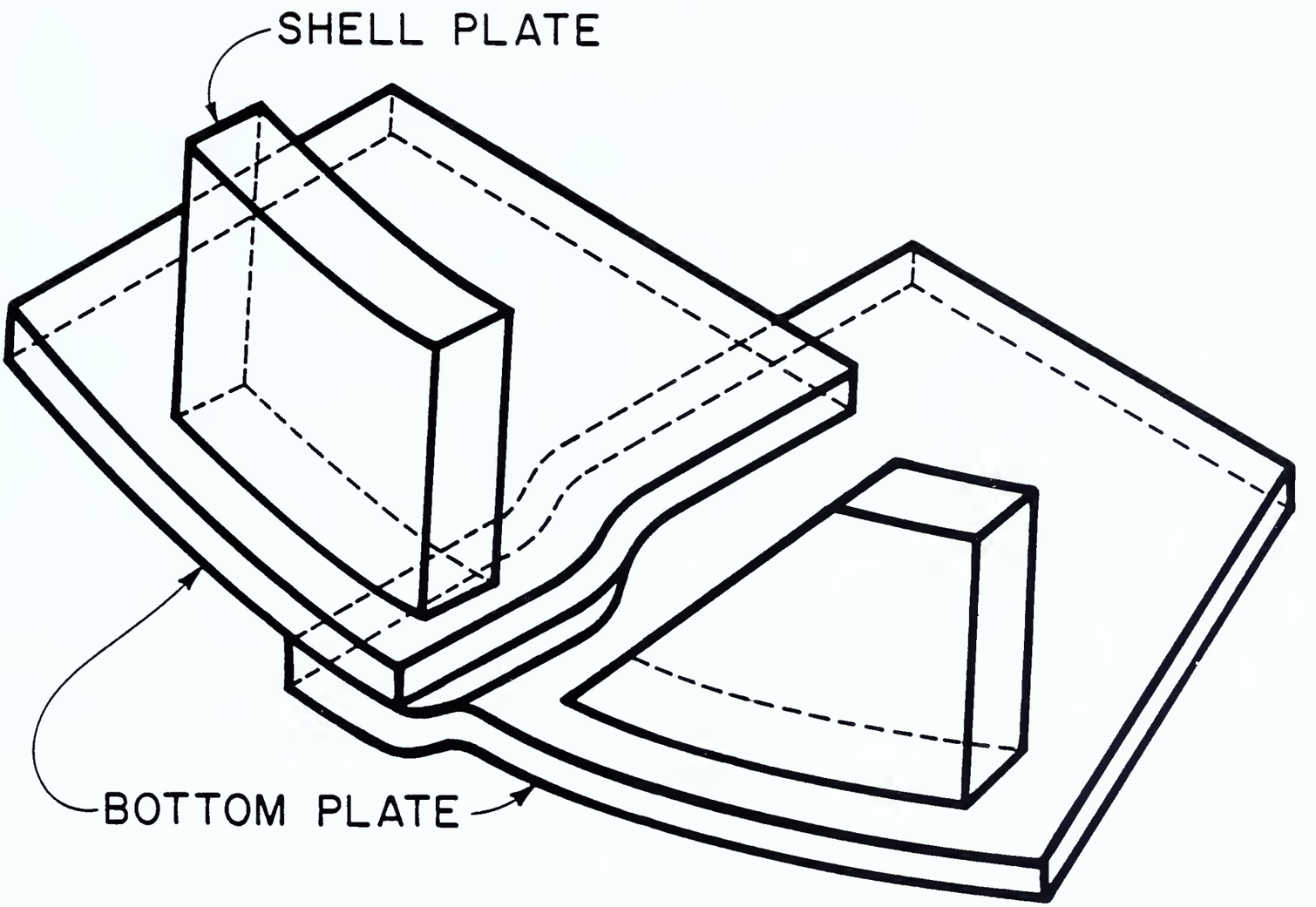


Fig. 18 - Base plate lap joint detail. (Courtesy American Petroleum Institute)

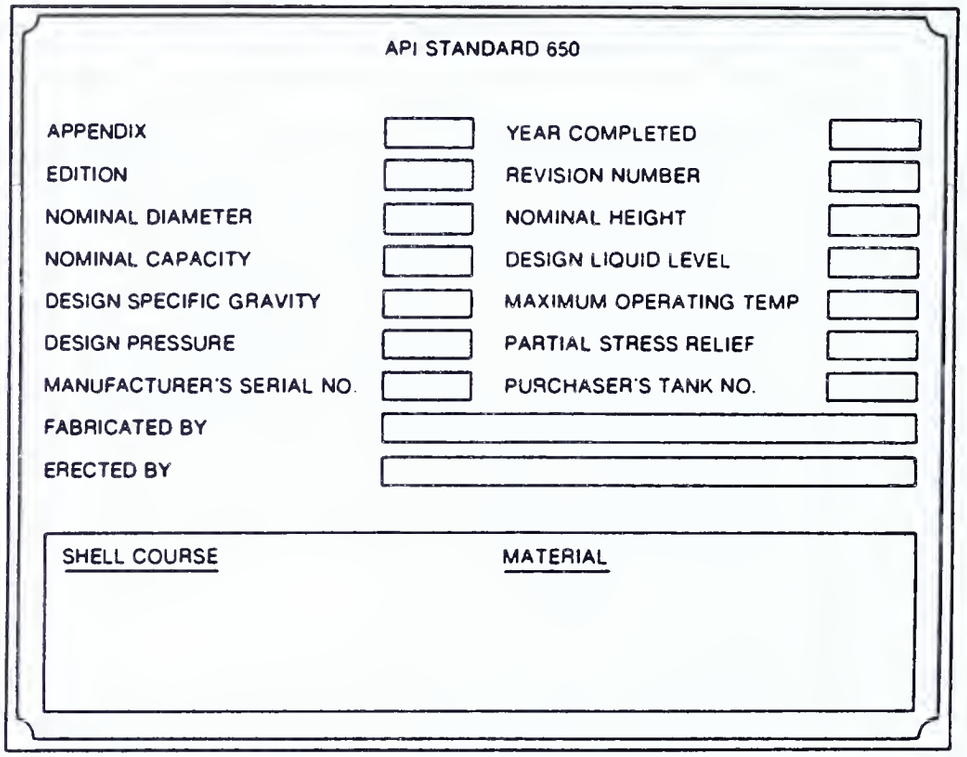


Fig. 19 - Sample tank name plate. (Courtesy American Petroleum Institute)

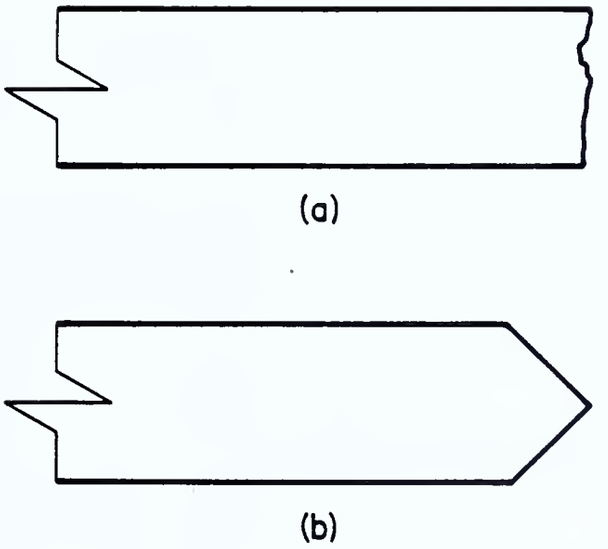


Fig. 20 - Cross-sectional idealized view of plate edge. (a) shows the course edge after cutting; (b) shows the edge ''prepped'' for welding.

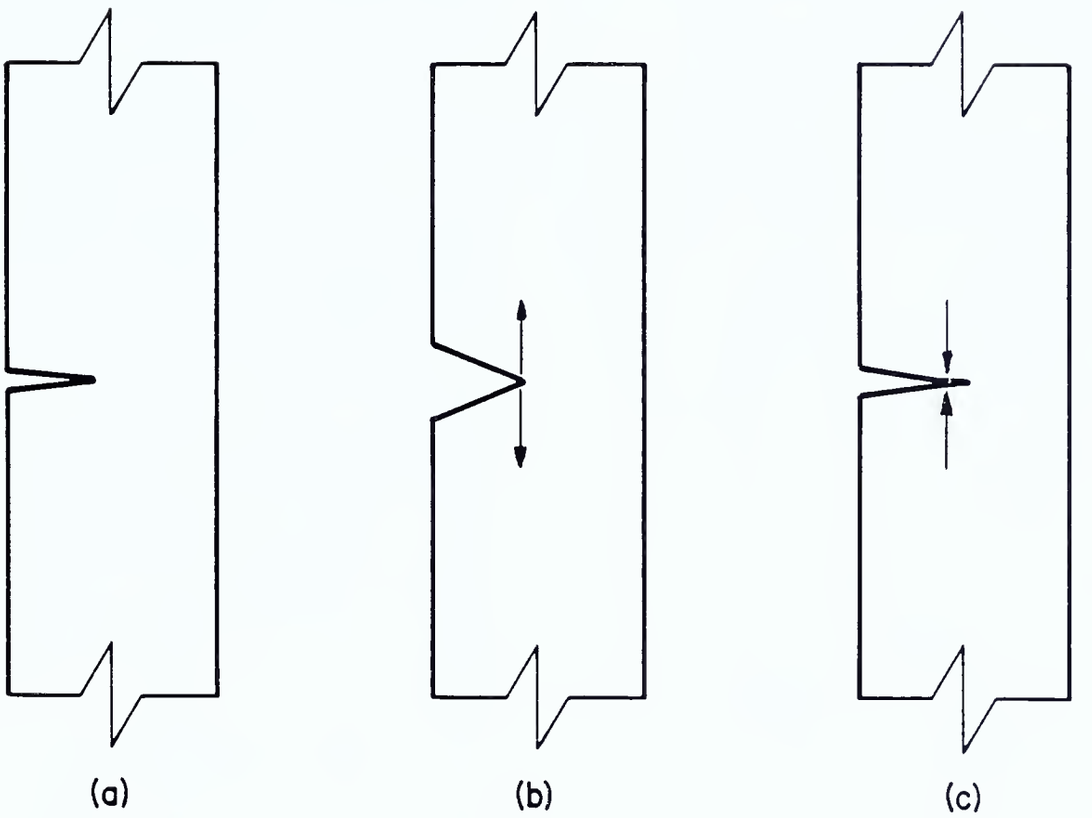


Fig. 21 - Illustration of ''Crack Blunting'' Three idealized cross-sectional views of a sharp tipped crack are shown. The crack prior to hydro-test is shown in (a); during hydro-test in (b) and after hydro-test in (c).

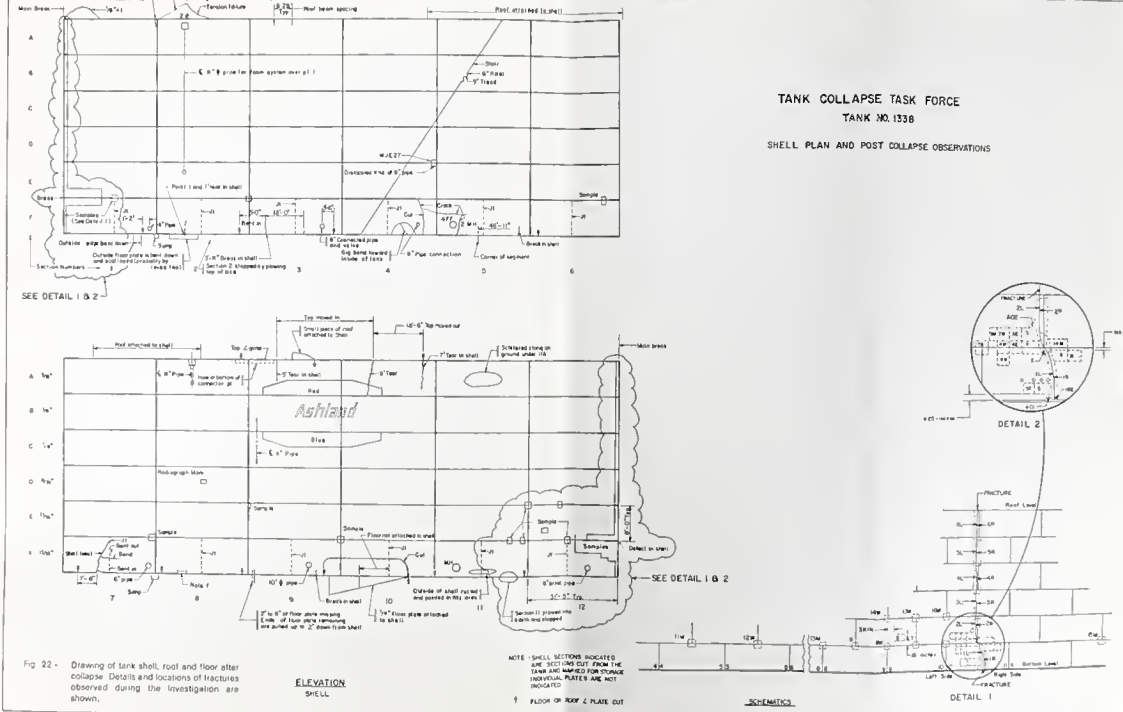
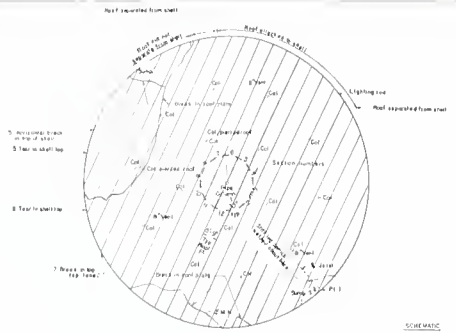
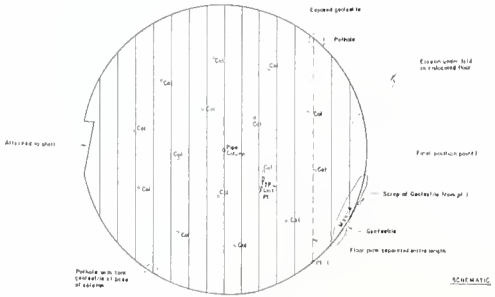


Fig 22 - Drawing of tank shell, roof and floor after collapse. Details and locations of fractures observed during the investigation are shown.



ROOF PLAN AND POST COLLAPSE OBSERVATIONS

TANK COLLAPSE TASK FORCE
TANK NO 1338



FLOOR PLAN AND POST COLLAPSE OBSERVATIONS

IV. VOLUNTARY AND GOVERNMENTAL REGULATION

A. Introduction

At a time when governmental regulation is frequently depicted as so pervasive that it almost seems a homeowner needs a building permit before installing a smoke detector, there was inevitably immediate speculation that Ashland must have run afoul of numerous local, state, and federal controls of the construction and use of Tank 1338. As will develop, however, the patchwork quilt of applicable laws leaves petroleum storage tanks often uncovered. It is true that Ashland failed to secure the necessary fire marshall's permit and may have failed to implement a proper spill prevention and control plan. It is exceedingly unlikely, nonetheless, that faithful compliance with either of these requirements as they are presently enforced would have disclosed the conditions leading to the collapse.

This section of the report will review the various voluntary and governmental requirements and standards presently applicable to the construction of new — and reconstruction of used — storage tanks. Since the focus of the investigation was on above ground liquid petroleum storage, the emphasis in this analysis will remain consistent. Similarly, the concentration will be on state authority, not federal, in order to more effectively assist members of the Pennsylvania executive and legislative branches of government in evaluating the extant regulatory framework.

There are a number of voluntary or trade codes which provide the general bases for design and construction standards for petroleum storage tanks. These have been extensively discussed earlier. The American Petroleum Institute Standard No. 650-1980, Welded Steel Tanks For Oil Storage, is undoubtedly the most exhaustively developed, extensively detailed, and widely recognized and utilized of these standards. Notwithstanding ambiguity about its applicability to reconstructed tanks, it also provides the most comprehensive scope. The Underwriters Laboratory, Incorporated, Subject No. 142, Standard for Steel Aboveground Tanks for Flammable and Combustible Liquids, covers some of the same ground, but by its terms is limited to tanks of 50,000 gallons and less in capacity and to tanks of new material. One or both of these specific standards is usually adopted by other agencies or organizations, which understandably prefer not to undertake the laborious process of developing their own standards.

Traditionally, local officials provide the first line of defense against shoddy building practices. Indeed, the model municipal codebook, the BOCA (Building Officials and Code Administrators) National Building Code, contains a brief section requiring that main storage systems for flammable and combustible liquids be constructed and installed in accordance with NFPA-30. The National Fire Protection Association standard incorporates API-650 and UL-142 as its construction requirements.

However, the Floreffe experience is emblematic of the key shortcoming of municipal enforcement — its lack of uniformity. BOCA provides model provisions, but not every governmental unit wants to or will implement and enforce all of its sections. Jefferson Township in fact did not require a building permit for aboveground oil storage tanks. Other municipalities require a permit but perform very little meaningful review because of inexperience with building and construction concepts unique to liquid storage tanks. Large towns and cities, in the discretion of their licensing offices, sometimes require drawings and engineering certifications. Again, however, the precise pattern or practice varies widely from municipality to municipality.

B. The Fire Marshall Program

The most consistent and presently most relevant point of governmental intervention

occurs with the review and approval by the fire marshall of combustible liquid storage activity. The State Fire Marshall Law, originally enacted in 1927, provides that:

> The Pennsylvania State Police may adopt and enforce rules and regulations governing the having, using, storage, sale, and keeping of gasoline, naphtha, kerosene, fuel oil, or other substances of like character.

35 P.S. §1181. Pursuant to this authority, the State Police have promulgated regulations, codified at 37 Pa. Code §11.1 *et seq.*, prescribing the conditions under which flammable and combustible liquids must be used, stored, and otherwise controlled.

The purposes of this report will not be substantially advanced by parsing these regulations in their entirety. Several critical provisions, however, are particularly germane and deserve mention. The regulations by their terms prohibit the use, storage, or sale of flammable or combustible liquids with flashpoints below 200° when aggregated in excess of 30 gallons unless written approval is obtained from the fire marshall. 37 Pa. Code §§11.2-11.4. The regulations specifically recite that no person shall "install, replace, or relocate any tank ... for use with such liquids unless written approval ... is obtained from the fire marshall." These regulations apply to above and below ground tanks as well as inside storage tanks. 37 Pa. Code §§13.1 *et seq.* The proscriptions found in this chapter regulate minimum distances from property lines and buildings for various types of tanks and liquids, as well as minimum spacing between tanks themselves. 37 Pa. Code §§13.1-13.2. The regulations, obviously, also identify the approved methods for venting tanks and providing emergency ventilation in case of fire. 37 Pa. Code §13.8. In addition, the regulations also contain provisions concerning anchorage of tanks, dikes and walls, valves, and grounding. 37 Pa. Code §§13.4, 13.6, 13.9, and 13.10.

The Fire Marshall regulations also contain standards for design and construction of steel atmospheric tanks for combustible liquids. The minimum requirements are imported from various industry and research group standards, many of which have already been introduced. Indeed, Section 13.7 specifically refers to UL-142 (1981) and API-650 (1980) for requirements for the type of welded steel tank employed by APC at its Floreffe terminal. 37 Pa. Code §13.7. The Fire Marshall rules also require strength and tightness testing in accordance with the applicable standard before a tank is placed into service. The pertinent regulation goes further, specifying that the test be made at the tank's operating pressure "with air, inert gas or water prior to placing the tank in service." 37 Pa. Code §13.11.

While these provisions may appear comprehensive, the emphasis in their application is somewhat narrower. It is unlikely that any person involved in the day-to-day enforcement of this codebook would dispute that the focus, as the subtitle "Flammable and Combustible Liquids Handbook" suggests, is on fire and fire prevention concerns. The present State Police Fire Marshall, Captain Joseph A. Robyak, recently stated forthrightly in public testimony that, "these regulations are primarily a safety code as opposed to an environmental code." Indeed, Captain Robyak explained that inspection of tanks with regard to construction details, such as welds, rivets, and so on, is not a specific component of his work.

According to Captain Robyak, the procedure for securing the necessary permit is relatively straightforward. The prospective tank owner (in all counties except Allegheny and Philadelphia) submits an application to the State Police Fire Marshall which briefly describes the size and location of the structure, the number and kind of pumps, and several other pieces of information. The form is accompanied by a drawing which usually locates the tank in relation to other structures of concern. These documents are reviewed, generally by non-engineers, to ascertain whether distance, venting, and other similar requirements of the regulations have been met. If the application demonstrates compliance, an approval is issued. Following construction, a field inspector from the Fire Marshall's Office inspects the actual location to confirm that the installation is consistent with the approval, that fire safety equipment is adequate, and that electrical equipment is in conformance with the National Electric Code. No further site inspections would routinely occur.

Allegheny and Philadelphia Counties are outside the jurisdiction of the State Police Fire

Marshall's office. Each has implemented its own program to regulate the use and storage of combustible and flammable liquids. While these programs substantially overlap the statewide effort, they have some unique elements. Allegheny County has adopted its own fire code, but it is essentially identical to the State Police regulations. Thus, the sources of construction standards for tanks are again API-650 and UL-142. The county office also performs a comparable review of applications and drawings, which convey limited information, and conducts a site inspection to establish conformity.

Allegheny County Fire Marshall Martin Jacobs' office, however, does add one additional layer of review. It requests notification in advance of pressurized air or water testing in order to send a representative to observe. In the event that no representative can attend, the office requires a written certification of the test from the company or individual.

Philadelphia County has drawn its own fire code. While it does not precisely track Title 37 of the Pennsylvania Code, it covers essentially the same subjects. The Philadelphia Code incorporates NFPA-30 for its tank construction requirements. That standard, in turn, adopts the specifications of API-650 and UL-142.

Philadelphia does extend the statewide and Allegheny County practices in its implementation. Plans and diagrams are required to be submitted to the licensing and inspection bureau, where they are reviewed by professional plans examiners. Additionally, tank installation, alteration, and testing contractors must secure licenses from the City before they can carry out their trade. Examination for licensing focuses largely on fire prevention issues. Thus, the installation or alteration of a tank must undergo a permit review, and must be carried out by a vendor identified by the City as qualified. Tank testing must also be conducted and certified by a licensed contractor, which may be a tank erector or a firm which only does testing.

Philadelphia also attempts to have a representative witness the testing of a completed tank. It is considering adding a requirement that testing be covered by a permit in the same manner as are installing and altering.

It is important to understand expressly not only what these programs do examine, but also what they do not closely review. The fire marshalls do not as a general practice inspect or approve construction plans, material characteristics analyses, or welding procedures. They do not review the number and location of radiographs shot, nor do they examine the results of radiographs. They do not employ engineers to assist in determining compliance with API-650 or UL-142. Further, it is probably fair to say that, on balance, fire response and arson investigations are higher office priorities than regulation of storage tanks. This low prioritization is commensurate with the penalty applicable for violation. Failure to comply with the state regulations subjects the offender to a summary prosecution with a maximum fine of only $200.00. 35 P.S. §1183. Consequently, there is neither the interest nor resources available to aggressively monitor storage tank use. Inspections after initial approval and installation, for example, are quite rare. In this regard, it is also noteworthy that the Allegheny Fire Marshall's Office did not pursue the failure of Ashland to complete its application after the initial dialogue between Walters and Kelley.

Thus, it is exceedingly unlikely that faithful compliance with this permitting process would have prevented the collapse of Tank 1338. Outside Allegheny and Philadelphia Counties, it is probable that APC would have followed exactly the same course, with the exception of securing a permit based on a drawing and simple application form. In Allegheny County, the Floreffe terminal would presumably have been required to perform a water test, although it is possible that APC would have attempted to assert that the oil penetrant test, performed by STC to an uncertain extent, sufficed. Since the Fire Marshall's Office was not knowledgeable about API-650, invocation of the penetrant test might have prevailed.

Even a full water test in June of 1987 might very likely not have disclosed the initial flaw. As has been noted previously, the defect's ability to initiate a brittle failure is linked to the toughness of the metal. A test in balmy spring or summer weather would not have posed a valid challenge to the steel's tendency to suffer a cold weather brittle failure. Consequently, even at its most effective levels, the fire codebook would probably not have prevented this collapse.

C. Environmental Programs

With the exception of these fire marshall activities, whose emphasis is avowedly upon fire safety, there is no statewide regulatory program overseeing the construction and maintenance of large aboveground petroleum storage tanks for the purpose of preventing catastrophic failures. There is no statewide regulation of contractors who erect these tanks, nor is there a requirement that a permit be secured approving the precise construction practices and specifications to be followed in the assembly process.

The primary state authority to regulate inherently polluting substances and prevent degradation of ground and surface waters is the Pennsylvania Clean Streams Law. That statute attempts to advance the legislative purpose of preventing future pollution to the waters of the Commonwealth, and reclaiming those waters which presently are polluted. 35 P.S. §691.4. To accomplish these goals, the Department of Environmental Resources ("DER") is authorized to adopt any necessary rules and regulations. 35 P.S. §691.5. More specifically, when DER finds that an activity involving, *inter alia,* storage of substances, creates a danger of pollution, it may require by regulation that such activity only be conducted by permit and pursuant to conditions determined by DER to be necessary. 35 P.S. §691.402.

DER has not to date determined that the storage of large volumes of petroleum product, as a specific category of activity, requires a permit. The closest regulatory provisions appear in Chapter 101 of its rules, entitled "Special Water Pollution Regulations." 25 Pa. Code §101.1 *et seq.* Under these regulations, a permit is required for any impoundment or interconnected impoundments of polluting substance in excess of 250,000 gallons, or any combination of impoundments on one tract in excess of 500,000 gallons. 25 Pa. Code §101.4(c). Although petroleum products will easily satisfy the applicable definition of "polluting substances," there is substantial ambiguity about whether storage tanks qualify as "impoundments." This term is defined as "any depression, excavation, or facility situated in or upon the ground, whether natural or artificial and whether lined or unlined." 25 Pa. Code §101.1.

The common sense image of an impoundment is of a storage unit located primarily below the surface of the ground. Much of the definition — "natural," "depression," and "excavation" as well as "lined or unlined" — advances that concept. The inclusion, however, of the words "or facility situated in or upon the ground" introduces some uncertainty. A storage tank must be a facility as the term is used here, and, at least until the law of gravity is repealed, it rests in or upon the ground. Thus, an argument can be made that DER presently enjoys legal authority to require permits for these tanks.

There are several problems with this analysis, however. First, while the argument can be advanced, it is by no means assured of success should a tank owner seek to challenge such an application in an administrative or legal proceeding. The interpretation described above indisputably requires a literal, narrow reading of the regulatory language and is certainly at odds with a common sense approach. Second, the remainder of the regulation lacks any detail or specifications for construction standards that DER would apply in issuing permits under such a program. As a result, the agency would have to exercise virtually unconstrained discretion in determining application requirements and performance standards. Finally, and most significantly, DER does not now interpret Section 101.4(c) as authorizing or defining a storage tank permitting requirement. DER, based on its interpretation, has not developed any expertise in this area. In short, it does not presently require or issue permits and is doubtful of the wisdom of initiating a program under such dubious authority.

The remaining sources of potential authority for present regulation of construction and maintenance practices at aboveground petroleum storage facilities can be found in various Commonwealth and federal spill prevention and control requirements. A comprehensive analysis of existing spill control and response regulations is outside the scope of this investigation. In fact, intensive reviews of such requirements and their effectiveness in light of the Ashland collapse are presently in progress by other agencies or working groups. Nonetheless, a brief review of the pur-

pose and scope of such governmental oversight helps to round out the full picture.

Pennsylvania presently requires that any person storing polluting substances, such as petroleum products, take all necessary measures to prevent the substances from reaching the waters of the Commonwealth, whether by accident, carelessness, maliciousness, or any other cause. 25 Pa. Code §101.3. Petroleum marketing terminals are specifically required to prepare plans setting forth the nature of their activities and the nature of their prophylactic measures. 25 Pa. Code §§97.63(c), 101.3(b). These plans are called Preparedness, Prevention and Contingency, or PPC, plans. The current acronym, which is also used to describe the emergency planning required of hazardous waste generators, transporters, and disposers, replaces PIP, the previous, more parochial Pollution Incident Prevention plan required only by the water quality bureau of DER.

An examination of guidance documents issued by DER to assist in implementing this requirement, as well as a review of actual PPC plans, readily reveals that the primary emphasis of the program is on post-spill reaction. Facilities are required to maintain and describe their on-site system for containing materials after a release, to maintain and describe their emergency notification procedures, to describe their emergency training program for employees, to identify their clean-up contractor, and to explain their evacuation plan. Although some attention is directed to inspection procedures, the aim once again is to identify possible leaks and origins of discharges promptly. There is no suggestion that a facility is accountable to the Commonwealth through its PPC plan for tank construction details or major engineering analyses. Moreover, PPC plans do not automatically require prior review and approval by DER. The maintenance of a comprehensive plan at an oil storage facility will satisfy the requirements.

A comparable program is administered by the United States Environmental Protection Agency pursuant to the authority of the Clean Water Act, 33 U.S.C. §1251 *et seq.* The federal program, requiring Spill Prevention Control and Countermeasure plans, is narrower than the Pennsylvania program in certain respects. 40 C.F.R. §112.1 *et seq.* It is limited exclusively to preventing and controlling discharges of oil and related materials. It is also restricted in its coverage to the protection of surface waters, and therefore does not include groundwater protection. 40 C.F.R. §112.3. The enabling regulations, however, are significantly more detailed in describing the contents of SPCC plans, and require certification by a registered professional engineer, 40 C.F.R. §112.7. The EPA's philosophy is that an SPCC plan should primarily be designed to prevent the occurrence of spills and secondarily to provide an effective procedure to control oil spills on site. Nonetheless, the only provision of the applicable regulations that addresses overarching prevention issues, *i.e.*, construction practices, is rather flaccid. Section 112.7(e)(2)(i) merely provides that "[n]o tank should be used for the storage of oil unless its material and construction are compatible with the material stored and conditions of storage such as pressure and temperature, et cetera." While this undoubtedly expresses the appropriate sentiment, it hardly provides the specific guidance or detail necessary to forestall repetitions of the January 2, 1988 catastrophe.

In sum, the SPCC regulations, no less than the state PPC requirements, direct the facility operator's gaze to post-construction preparedness. Spill prevention efforts as presently constituted will neither prevent nor uncover the kind of initiating flaw responsible for the collapse of Tank 1338.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Statutory Recommendations

In evaluating the wisdom of creating any new governmental regulatory program, consideration must be given not just to the magnitude of the harm sought to be minimized or eliminated but as well to the frequency of its recurrence. Incidents or conditions which threaten widespread but not generally life-threatening impacts might conceivably occur so infrequently that extensive regulation and bureaucratic intrusion will fail to gain political or popular support if costs are measured against benefits.

An argument relying upon this rationale was advanced in the days immediately following the collapse of 1338, when attention was directed to the possible need for legislation regulating the construction and use of petroleum storage tanks. These tanks fail catastrophically and without warning so infrequently, the argument went, that they were of a piece with the biblical great flood — exceedingly uncommon and essentially unpreventable. To impose a regulatory program on petroleum storage facilities in the hopes of preventing these steel clouds from opening up, the inference of the argument concluded, was simply unjustified. The cost of any such program far outstripped its value.

The preceding sections of this report compellingly demonstrate that this disaster was eminently preventable. The other anchor of the anti-legislation argument — that these incidents are rare — simarly finds no purchase in recent history. Indeed, according to the testimony of Richard S. Golob, Director of World Information Services, before the U.S. Senate, the Ashland tank spill is not particularly unique. Mr. Golob presented a revealing inventory of recent major spills and discharges caused by structural failures. For example, in June of 1985 a North Carolina storage tank ruptured within a year after repairs had been made to it. Approximately 800,000 gallons of asphalt spilled out of the tank. In February of 1985, a valve ruptured on a storage tank in New York, allowing 390,000 gallons of diesel fuel to discharge to the ground. A 1983 foundation collapse in New Jersey caused a tank to tilt and rupture lines, permitting 420,000 gallons of No. 6 fuel oil to escape. Two million gallons of diesel fuel spilled from a ruptured tank in North Carolina in 1982. Outside the continental U.S., 520,000 gallons of fuel oil discharged from a Puerto Rican tank which ruptured in 1978, and in 1986 an enormous Panamanian storage tank of crude oil ruptured and spilled its entire contents, some ten million gallons.

In all, Mr. Golob could account for at least nine major spills since 1978 attributable to structural failures. Less recent history, as recounted earlier in this report, evidences a similar pattern of recurrence. While each of these failed tanks suffered from a different specific instantaneous cause than did Tank 1338, they nonetheless each harbored a structural weakness which caused them to founder. A blinkered reaction based only upon the Ashland situation might well result in casting a net so narrowly that it fails to catch all the fish of interest.

One difficulty must be acknowledged before recommendations can be intelligently presented. As a result, presumably, of the absence of governmental involvement in aboveground storage activities, there is a serious paucity of reliable data about the number of storage tanks in use. The actual number, of course, will be controlled by the kinds of tanks that are included in any inventory — all tanks, only tanks above a certain size, atmospheric tanks, only storage as opposed to production tanks, only petroleum product tanks, etc. DER presently estimates that there are a minimum of 6500 bulk (capacity greater than 50,000 gallons) aboveground storage tanks and perhaps 30,000 more smaller tanks in Pennsylvania. These figures, however, are derived from an almost ten year old review of maps and aerial photography.

There is no great confidence in the accuracy of these numbers. Moreover, at best they provide only a snapshot of conditions at one particular moment, not a description of trends and developments. For example, major oil companies almost

uniformly explained to investigators that very little tankage is presently being built. These companies find it more economical to maintain much leaner inventories to enable them to respond rapidly to fluctuating oil prices. The increasing reliance on pipelines to deliver product only as needed also suggests that large storage tanks may someday become the dinosaurs of the twentieth century.

Nonetheless, a significant number of these enormous storage facilities still dot the landscape. Their continued freedom from any effective governmental regulation makes it almost certain that more will fail, with serious consequences, in the future.

Based upon its review of the conduct of the principals involved in the construction of Tank 1338, its review of applicable industry standards and practices, its review of the incidence of comparable failures, and its review of the current relevant laws and regulations, the Tank Collapse Task Force has developed several recommendations. These are set forth below, with commentary where appropriate.

1. **The General Assembly should adopt legislation authorizing comprehensive regulation of the construction and maintenance of aboveground petroleum storage tanks.**

The Task Force has concluded that strict attention to structural soundness and construction practice is essential to minimizing future failures, which are otherwise likely to occur on an irregular and unpredictable basis. Further, the Task Force has concluded that the governmental interest in protecting its citizens from the environmental, health, and safety consequences of such disasters is within its police power and justifies the enactment of legislation to oversee the construction and use of petroleum storage tanks. Finally, the responsibility imposed upon the Commonwealth pursuant to Article I, Section 27, of the Pennsylvania Constitution to act as conservator of natural resources for generations yet to come virtually compels the creation of governmental authority to prevent the injurious environmental implications of future incidents.

The drafting of specific model legislation to implement this conclusion is beyond the scope of this investigation. Moreover, the Task Force does not believe that, as an investigative and advisory body, its role extends to commenting upon the several legislative proposals which have already been offered in response to this now-widely perceived statutory shortfall. The Task Force, however, has developed several conceptual suggestions which it offers in the interest of advancing the legislative discussion.

Any legislation addressing this issue must, as its *raison d'etre,* invest a state agency with the authority to promulgate rules and regulations prescribing the standards to which petroleum storage tanks shall be built and maintained. These standards should not expressly be incorporated in a statute but promulgated through agency regulations, which are more appropriate for oft-changing technical details.

In general, the Task Force finds that the construction and material specifications of API-650 are sufficiently conservative to serve as the technical basis for any governmental regulation. The standard has been developed by knowledgeable experts from various interested disciplines, is subjected to constant review and revision to reflect technical advances, and enjoys widespread recognition and application. This is evidenced by its adoption by the American National Standards Institute.

A few cautionary notes are applicable, however. API-650 was designed as a voluntary industry standard, not as a legally enforceable regulation, and its text is therefore replete with sections and phrases which are imprecise, ambiguous, precatory, or some combination of all of these. Several examples readily demonstrate this. For instance, some uncertainty persists as to whether API-650 even applies to rebuilt, as opposed to new, tanks. Another introductory provision, Section 1.1.2, patently authorizes disregard for all the specifications which follow by stating that, "This standard is for the convenience of purchasers and manufacturers... and is not intended to prohibit [them]... from purchasing and fabricating tanks meeting specifications other than those contained herein." In the same way, material toughness requirements are precisely specified in Section 2.2.9.3 but then substantially vitiated by the sweeping and subjective qualifier, "Unless experience or special local conditions

justify otherwise...." Furthermore, certain integral aspects of tank construction, such as the foundation, are either absent from API-650 or relegated to non-mandatory appendices. Finally, the now legendary water test requirement is limited by the words "If water is available for testing...." While API's literal construction of that condition is heartening, the word "available" is virtually a license for creative lawyering if an enforcement action were to follow some failure to hydrostatically test a tank.

In short, while the technical requirements of API-650 are unassailable, the language with which they are described is not. The Task Force recommends careful analysis of the standard's provisions before they are adopted or incorporated into law or regulations in order to avoid controversy about their meaning and applicability.

Moreover, reliance upon an external trade organization, which is capable of implementing changes to its recommended standards in a relatively expeditious manner, places a great responsibility on the administering state agency to monitor the voluntary standard and integrate such improvements into regulation. Untenable enforcement situations will arise if tanks are constructed in conformity with currently applicable API standards but in violation of regulations which have lagged behind recent revisions.

This is not an insurmountable problem. Almost every state has adopted portions of the ASME Boiler and Pressure Vessel Code into law. ASME is also a private industry organization, not bound by the strictures of government rulemaking. Yet this regulation has worked relatively well over the years, and brought the public real benefits in the form of safer equiment.

Any effective statute must encompass several elements. Existing tanks present different risks to the community, and represent different resources to their owners, than do new tanks. The installation or construction of any new tank, or major modification or repair to any existing tank, should require a permit from the agency. Experience has shown that there is an increased risk of tank failure after modifications or repairs. All tanks should be registered and require periodic reregistration, which might coincide with standard industry annual tank inspections. Reregistration should be used to identify changes in service use or maintenance incidents of significance. Through a phased registration process, all existing tanks can have their integrity demonstrated over a period of years as they undergo the routine out-of-service inspection to which they should be subjected. The registration process will also serve to establish a more reliable inventory of tanks.

The Task Force has specific recommendations about testing, as well. New tanks as a function of their construction permits and existing tanks during out-of-service inspection for initial registration should have full hydrostatic tests performed. Additionally, it is recommended that such testing be administered during cold weather to provide a more valid measure of tank behavior under potentially low toughness conditions. While API prescribes the water test only as a strength indicator, it can also test material toughness under appropriate conditions. Problems from cold weather for the test can easily be overcome. Freezing can be avoided by such means as mechanical agitation, chemical addition, or temporary heating.

Additionally, new and existing tanks on the occasions noted above should be subjected to close inspection of all vertical welds and "T" welds by qualified inspectors. Tanks for which mill certificates are lacking should have coupons removed and the steel verified for toughness and other properties specified by API-650.

Reconstructed tanks are not inherently unsafe. A tank erected two years ago with modern materials but moved recently and rebuilt competently may make a better neighbor than a forty year old museum of discarded materials and outmoded practices that is still in use. Nonetheless, dismantling and rebuilding do highlight several important issues, including structural alterations, changes in service use, and disassembly practices. Permit applications for reconstruction should specifically require all necessary information to evaluate potential risks.

Storage tank legislation should also require tank owners and operators to demonstrate sufficient financial responsibility to be able to undertake corrective action and compensate private citizens for losses they may suffer from discharges. While companies of Ashland's magni-

tude will ordinarily have insurance and/or assets available to defray such costs, smaller firms may lack the financial resources to address the substantial damages that total failure of even more modest storage tanks can cause. Since many of the members of the storage community may be these relatively small businesses, the legislative process should examine creative methods of allowing demonstration of financial responsibility. For example, guarantees of a specified minimum resource from tank owners supplemented by contributions from a fund comprised of tank registration fees, or other industry sources, may be appropriate.

The Task Force offers several other observations. Although arguments can be made that responsibility for administering a new legislative program of this type should be entrusted to the Department of Labor and Industry or the Department of General Services, it is much more likely that it will be assigned to DER because of the obvious potential for pollution associated with these storage tanks. Indeed, there are some obvious benefits which might be realized if the same agency regulates both pre-incident structural soundness and post-incident preparedness and response. Fundamental design improvements may result if an agency with responsibility for both encourages the perception that original design, in-service inspection, maintenance, and post-spill response are part of a single continuum, not unrelated components of industry activity.

Nonetheless, the Task Force cautions that a new program to regulate these tens of thousands of structures could, without careful crafting, swallow other DER activities and priorities. There is no obvious reason that legislation could not establish a state-private sector partnership to implement any regulatory program. Such a partnership might take the form of a program where construction, inspection (for registration purposes), and testing may be conducted only by firms licensed or certified by the state. Alternatively, certification of construction plans and registrations fees by a knowledgeable, registered Professional Engineer, not employed by the tank owner or operator, might prove workable. These two examples, by no means the only possible approaches, illustrate ways in which demands for additional state staffing requirements could be minimized.

The Task Force also notes that a desire to assign more comprehensive oversight of these storage facilities to an agency not now exercising it does not inexorably require shifting all present fire marshall activities along with the new program. Inspections related to combustible or other incendiary conditions, as well as fire response and arson investigations, should remain with the State Police and county Fire Marshall's Offices. Those agencies have developed expertise, acquired equipment, and integrated effectively with the rest of the fire prevention community. There is no discernible justification for disrupting the activities these offices presently carry out.

Finally, it is important to recall that consideration of the use of other kinds of tanks and storage of non-petroleum products—such as pressure vessels and chemical storage—was outside the scope of this investigation. Consequently, no recommendations about regulation of these activities are included. This omission should not be construed as endorsement of the present regulatory structure for those activities.

2. Legislative attention should also be directed to problems from underground tanks.

While bulk aboveground tanks present a risk of large-scale surface failure, underground tanks present the far more insidious threat of groundwater contamination from leaks and discharges that occur more gradually and much less obviously. Indeed, the environmental significance of product losses from underground tanks may dwarf that of aboveground tanks; New Jersey, for example, has encountered a 37% underground leaking tank rate in one of its environmental assessment programs.

This problem has not gone unnoticed by the federal government. Almost four years ago, the Congress enacted the Hazardous and Solid Waste Amendments of 1984, which provided for the development and implementation of a comprehensive regulatory program for underground storage tanks. In the Superfund Amendments and Reauthorization Act of 1986, the Congress authorized EPA to clean up releases from underground tanks or require their owners to do so, and established a trust fund to help finance some of these activities.

Characteristically, these statutes encourage states to develop programs containing requirements "no less stringent" than those found in federal law and authorize delegation of the regulatory effort to states which establish qualifying programs. In brief, a state underground storage tank program can receive EPA approval if it requires:

1) a leak detection system;

2) maintenance of inventory and testing records;

3) reporting of releases and responses;

4) implementation of corrective measures;

5) closure of certain tanks;

6) evidence of financial responsibility;

7) performance standards for new tanks; and

8) notification to the state of the operational status of tanks.

Under certain circumstances, EPA may also provide limited funding to support qualifying state programs.

Any comprehensive examination of underground storage tank practices and issues is outside the scope of this effort. There already exists a far-reaching federal statutory scheme to serve as a model for state efforts. Moreover, there are substantial differences—in addition to the obvious one—between aboveground and underground storage tanks. There seem to be far more underground tanks, and the incidence of small business ownership is greater. Aside from these disparities, which have direct regulatory implications, there are also technical differences. Underground tanks are never as large as the biggest aboveground storage units, and their walls, supported and protected by the surrounding earth, are subjected to far less static loading.

Nonetheless, the ultimate threat posed by these tanks is the same: unintended loss of product and resulting pollution. For this key reason, the Task Force urges that underground storage tanks not be orphaned legislatively in the rush to adopt requirements addressing aboveground tanks. It is probably true that no single, central, statutory provision could adequately address the disparate technical requirements for both classes of tanks. It is not obvious, for instance, that all of the federal underground tank requirements are applicable to aboveground units. At the same time, tests for structural integrity of aboveground tanks may be of little utility in assessing the soundness of underground ones.

Nonetheless, a storage tank regulatory program with some generic components might well be appropriate and effective. Enforcement powers of DER, for example, including right of entry, right to require production of documents, administrative order authority, and civil and criminal penalty powers, should be the same regardless of the type of tank. Any fund established to help pay for the cost of remedial actions could draw its monies from both classes of tanks in order to extend the financial base. Similarly, the state-private sector partnership referred to previously would be equally applicable to the regulation of belowground storage, and would soften the impact on staff resources from a new program.

In short, the Task Force recommends a comprehensive legislative response to the storage tank issue. A statute that authorizes the promulgation of different sets of technical regulations to address individually the unique problems of each tank class, but which also recognizes common regulatory and enforcement elements where appropriate, would substantially advance environmental protection in Pennsylvania.

3. The General Assembly should strengthen DER's cost recovery authority.

Environmental emergencies generally provoke extensive government response activities. In this instance, an employee of the DER arrived at the Floreffe terminal within one hour of the spill, and numerous additional DER employees and officials joined the response in the hours and days thereafter. No administrative order was issued by the agency to Ashland Oil, Inc., which had itself responded aggressively to contain and then remove the escaping diesel fuel. Neither did DER expend emergency funds to retain removal contractors; Ashland's response in this regard was also deemed adequate. Nevertheless, DER employees remained engaged in responding to the catastrophe, in some instances literally round-the-clock, for days at a time. They oversaw and supervised the activity of Ashland and its contrac-

tors, assisted local water suppliers, and provided a variety of community services.

In the face of this response, it is startling to learn that there is no unambiguous expression of authority under which DER can recover its costs for these activities. The Clean Streams Law provides only that "[f]or the purpose of collecting or recovering the expense involved in correcting the condition, the Department may assess the amount due in the same manner as civil penalties are assessed ...." 35 P.S. §691.316. In the Ashland situation, however, DER incurred no direct expenses in correcting the situation since its role was one of oversight, not participation. Thus, this section fails to provide an indisputable basis for recovery of these kinds of costs. Further, the word "costs" is not self-defining. It is impossible to discern whether it encompasses salary, overtime, administrative support, and so on. For the same reason, Section 605 of the Clean Streams Law, 35 P.S. §691.605, which authorizes recovering the "cost of restoration" of Commonwealth waters, is little improvement. Section 605 is doubly handicapped in that it is also expressly limited to no more than $10,000 per day.

The language of the Administrative Code, 71 P.S. §570-17(5), is similarly limited to recovery of the cost of abatement or removal of a nuisance and may not contemplate oversight expenses. Finally, the Administrative Code requires the owner or occupant of premises where an actionable nuisance exists to have failed to comply with a DER order before the agency can take direct abatement steps. Unfortunately, in some cases, such as emergencies, the issuance of an order and evaluation of a recipient's degree of compliance are, to say the least, impractical. In other instances, such as the Ashland tank collapse, the responsible party responds appropriately but DER still incurs substantial administrative costs.

The Task Force concludes that these artificial distinctions between direct abatement activity and oversight, and between agency response in the absence of an ignored order rather than after the issuance of one, serve to penalize DER in circumstances where it has exercised its authority prudently and confer an unintended and unjustified economic benefit upon persons responsible for the original incident. The Task Force recommends that the General Assembly enact legislation which expressly authorizes DER to recover the costs of investigation, litigation, oversight, monitoring, sampling, testing, and other expenses necessary to an agency response to a violation of the laws which DER administers.

B. Voluntary Standards

Although the Task Force was not constituted as a technical group, its close working relationship with the provisions of API-650 over the past several months lead it to make several suggestions to the sponsoring organization, the American Petroleum Institute. Some of these ideas were submitted to the Task Force in witness or industry interviews, while others have grown out of the Task Force's own review of the facts here. API, as a private entity, is free to follow or disregard these suggestions. They are offered in a spirit of constructive commentary.

In many respects, API-650 is an ambiguous document. The language of many sections is vague or actually inconsistent with other provisions. The Task Force strongly suggests that API review the standard with an eye to reducing such discontinuities.

The tank design criteria in API-650 is based on strength criteria—the traditional method of structural design. Toughness of plates is handled by requiring them to have a certain Charpy V-notch toughness. As discussed earlier, the value and applicability of the results of Charpy tests are severely limited because the results themselves are only valid for particular specimens tested, and the relationship to the plates actually used is somewhat dubious. Fracture mechanics, however, now provides a method to actually design against brittle failure. "Leak before break" design creates a brittle failure warning system making such failures less arbitrary and spontaneous. The Task Force suggests that API revise API-650 to incorporate fracture mechanics design criteria.

The investigation has revealed the importance of proper inspection and review of work performed. It has also highlighted the importance of employing properly qualified employees and contractors. The Task Force believes that the overall safety of storage tanks would be improved if the inspection and testing provisions of API-650

were revised to remove ambiguity. A more complete description of the purchaser's inspection responsibilities is also advised. Finally, the Task Force suggests that API establish requirements governing qualifications of welders and others involved in tank construction.

API-650 is only applicable to tank construction, not to repairs. Since storage tanks often fail following repairs, the Task Force also suggests that API develop and implement a standard covering tank repair. Some companies have satisfied their own needs by creating internal repair standards, but none exists for the industry as a whole.

Through its published interpretations, which respond to questions about the meaning or application of various provisions, API does provide some guidance to users. However, the Task Force proposes that API go further and publish a commentary to accompany each standard. This is a common practice among purveyors of technical codes and standards. The American Institute of Steel Construction and the American Concrete Institute, for example, write and publish commentary which accompanies their codes.

Despite its importance, in-service inspection of petroleum storage tanks is not covered by a standard or code, but only by a guideline, called the Guide for Inspection of Refinery Equipment, Chapter XIII Atmospheric and Low-Pressure Storage Tanks. This document is valuable, within its limited purpose. It does not establish any inspection requirements, which are left to the owner's discretion. The Task Force believes that a code, with more defined requirements, would create some uniformity in the industry by giving terminal operators and others standards to follow. API has already promulgated a similar code applicable to ASME Pressure vessels, the Pressure Vessel Inspection Code, API-510.

C. Enforcement Options

The Task Force was formed as an *ad hoc* inter-agency investigative effort. As such, it enjoys no inherent enforcement or prosecutorial authority. In more straightforward language, it cannot initiate administrative, civil, or criminal action against any person or persons it determines were responsible for the collapse of Tank 1338. This inability to proceed in a legal forum, however, does not prevent the Task Force from making appropriate recommendations based upon the information it has developed.

4. The Commonwealth should pursue civil enforcement action for damages and costs against Ashland.

The conduct legally imputable to Ashland Oil, Inc., and Ashland Petroleum Company, as undertaken by several of the employees who were involved in the decision to relocate WI-16 and in the execution of that decision, was characterized by a pervasive pattern of neglect of industry standards and practices. Without repeating the entire saga, these significant and uncontroverted deviations from the appropriate standard of care included the failure to establish the steel's properties; the failure to consider the intended changes in service use and their implications for the steel's properties; the failure to implement Ashland's own internal recommendation to remove all old weld material; the failure to hydrostatically test the tank; the failure to secure the correct number of X-rays and X-rays in the prescribed locations; the failure to require correction of defective welds; and the failure to reject the tank or conduct more thorough inspection for defects upon notification that more than half of the weld areas examined did not satisfy applicable standards. More conscientious attention at any of these steps may very well have prevented the collapse.

This pattern of negligence makes Ashland Oil, Inc., and its subsidiary, Ashland Petroleum Company, directly and primarily responsible for the failure of Tank 1338 and thereby responsible for the environmental and public water supply effects which resulted from the sudden release of enormous quantities of No. 2 fuel oil. Accordingly, the Task Force recommends that the Commonwealth pursue civil enforcement action for maximum penalties and costs against Ashland pursuant to the provisions of the Clean Streams Law, Safe Drinking Water Act, and, if appropriate, under the Solid Waste Management Act and as a trustee of the State's natural resources pursuant to Section I, Article 27 of the Pennsylvania Constitution. The demonstrable negligence of Ashland should bear directly on the amount of the ultimate civil penalty.

5. **The Attorney General should consider whether criminal prosecution for polluting discharges is appropriate.**

The question of whether criminal prosecution should also be initiated is a far thornier one. The Clean Streams Law provides that negligent or willful violations of any of its provisions may be prosecuted as misdemeanors of the third degree and punishable, upon conviction, by imprisonment of up to one year or a fine of not more than $25,000, or both. This report provides ample evidence of negligent conduct by Ashland, through its employees, and it appears beyond doubt that the discharge of diesel products to the Monongahela and resulting pollutional effects violated various substantive provisions of the Clean Streams Law.

The existence of this authority to prosecute, however, does not mandate its exercise. Even without a conviction, the institution of criminal charges against a defendant is a profound and stigmatizing act. While the initiation of civil proceedings for compensation of environmental damages and recovery of costs — and even for some measure of punishment and deterrence — implicity alleges that a defendant has transgressed some of the rules of an ordered society, the lodging of criminal charges is an assertion that the defendant has engaged in activities totally outside the universe of conduct accepted as lawful. It has been observed by the Oregon Supreme Court, in a related context, that the charge that one has committed a crime is "the gravest act by which the state confronts one of its citizens." *State v. Freeland* (1983). For government to act responsibly, it must wield this great power wisely, consistently, and in a manner designed to advance significant societal goals.

It seems plain that the goal of a criminal prosecution for negligent discharge pursuant to the Clean Streams Law would not be financial recovery for the Commonwealth. DER and other agencies can seek to recover for environmental damages and costs pursuant to civil causes of action, which require a lower standard of proof by the government to succeed than does a criminal prosecution.

It is possible, however, that a criminal prosecution might deter repetition of similar conduct by other storage tank owners and operators. Yet, in the Ashland situation, it may be difficult to imagine that a criminal conviction for the lowest grade of misdemeanor would contribute significant additional deterrent effect beyond that implicit in the circumstances themselves. Notwithstanding the patent negligence described previously, it is nonetheless true that the collapse of Tank 1338 involved an unintentional loss of substantial amounts of petroleum product with a commensurately high commercial value to its owner. Thus, aside from the costs of responding to the spill and the costs of resulting private and governmental litigation for damages, Ashland has also suffered a financial loss from its inability to sell the No. 2 fuel oil which spilled and could not be recovered.

Accidental discharges or losses of product from spills of this type do not seem obvious candidates for criminal prosecution which has deterrence as its purpose. It seems self-evident that any facility operator—petroleum company or otherwise—should be deterred from discharging products accidentally not only because of the consequential response and litigation costs but also because of the squandered value of the lost material. Additional deterrence from a criminal prosecution for negligent conduct does not necessarily seem apparent or effective.

Nevertheless, the Pennsylvania General Assembly has articulated, in a clear voice, a standard of criminal culpability based upon negligent conduct. The legislature may have concluded that it is necessary to encourage a higher standard of care upon operators of potentially polluting facilities by exposing them to criminalization and accompanying stigmatization for negligence. Equally, the legislature may have recognized — quite validly — that the automatic deterrent value of a reduction in a defendant's pocketbook from losing commercial product might sometimes be trivial compared to the environmental harm resulting from the release. The General Assembly may also have intended by this penalty provision to entrust to a prosecutor the responsibility to identify those instances where the negligence was so rampant, or the consequences so far-reaching, that criminal prosecution was appropriate to express society's manifest disapproval.

Ultimately, the decision to bring a criminal prosecution under the Clean Streams Law must

rest with the appropriate prosecuting agency itself. It is there that the preceding factors must be weighed, along with the existing policy for sanctioning intentional discharges, the consideration to be extended to Ashland for its cooperation in the days and weeks after the collapse, the relative clarity or ambiguity of the voluntary industry code and practices which establish the relevant standard of care, the existence of civil grounds for relief, the likelihood that it could be proven that the failure was preventable, and numerous other factors. The Task Force is neither authorized nor competent to perform the feat of balancing these competing considerations.

The Task Force can, however, bring to the attention of the appropriate authorities its conclusion that the facts developed during its investigation appear to establish facial sufficiency of the elements of Clean Streams Law violations. Accordingly, the Task Force recommends that the Commonwealth ask the Pennsylvania Office of Attorney General to examine this report, and such other evidence as it may determine is necessary, in order to consider whether criminal charges under the Clean Streams Law should be prosecuted against Ashland Oil, Inc., and the Ashland Petroleum Company.

The Task Force also considered the possible application of traditional criminal prohibitions of certain kinds of reckless behavior. Specifically, possible prosecution for recklessly causing a catastrophe, 18 Pa.C.S. §3302(a), and reckless endangerment of another, 18 Pa.C.S. §2705, were examined. The moral opprobrium and expectation of punishment which might be lacking in the instance of negligent conduct are much more clearly relevant where recklessness is exhibited. While negligent conduct might not warrant a criminal prosecution which adds little deterrence, reckless conduct might well justify the punitive value of a prosecution.

Although quantifying the exact meaning of the term "catastrophe" has attracted judicial attention and remains difficult to define with precision, the Task Force concluded that the degree of widespread injury or damage normally associated with a catastrophe was established here. Similarly, the element of endangerment of another person, which is defined as conduct placing that person in danger of death or serious bodily injury, was accepted as provable in view of the ferocity of the actual collapse. Consequently, attention was necessarily focused on the legal meaning of recklessness.

Pursuant to the material provisions of the Pennsylvania Crimes Code, recklessness is the conscious disregard of a substantial and unjustifiable risk which exists or will result from a person's conduct. 18 Pa. C.S. §303(b)(3). This definition, which requires purposeful disregard of a risk, does not appear to measure well against the conduct of the Ashland employees involved in the project. While they routinely failed to comply with industry standards and practices, such omissions were almost always attributable to lack of information, misunderstanding of standards, or confusion about individual responsibility. The Task Force cannot identify a single instance in which a faulty decision was made under circumstances where all the necessary facts and potential consequences related to that decision were comprehended by the decision-maker. Moreover, there is no evidence extant which would suggest why the participants would want to disregard a substantial and unjustifiable risk that Tank 1338 would collapse. Neither cost-shaving, corner-cutting, nor time-saving were factors as significant in the decision-making as was simple ignorance.

Thus, the Task Force concludes that neither Ashland nor its employees acted with the degree of recklessness which the law requires to support a criminal prosecution in which reckless conduct is an element. This limited conclusion, however, should in no way be interpreted to exonerate or approve the profound lack of concern for details and inattention to standards which the company's practices demonstrated.

The Task Force does not recommend consideration of any criminal charges against individual employees. It is of course true that a corporation can only act through its employees. Nonetheless, no Ashland employee involved in the reconstruction project was found to have acted in a manner designed to advance personal, venal goals or in a fashion inconsistent with the conduct apparently expected of him by APC management. While criticism of specific employee actions was issued by supervisory officials after Tank 1338 failed, this disparagement — in view of the *laissez-faire* corporate environment during construction — is

more accurately understood as deprecating the ultimate result, not the employee conduct which precipitated it. Ashland's institutional practices allowed this disaster to occur, and the Task Force does not believe it appropriate to single out individuals criminally for their failure to rise above a corporate climate of carelessness and confusion.

6. **Skinner Tank Company is also liable for civil prosecution for the disaster.**

A similar analysis also applies to the civil culpability of the Skinner Tank Company. According to API-650, as the tank manufacturer STC was responsible for assuring the appropriateness of the material being used in Pennsylvania, responsible for radiography and hydrostatic testing, and generally responsible for compliance with all the provisions of the industry standard. Indeed, only design and preparation of a tank's foundation is assigned to the purchaser. API-650 establishes the relevant standard of care, and STC failed to satisfy that standard.

Consequently, STC must share responsibility for failing to perform those tests, measurements, and inspections which should have disclosed the flaw and low quality of the steel. The Task Force is aware of no formal agreements or understandings with Ashland through which STC attempted to relieve itself of these obligations. It is unclear, in any event, that STC could effectively delegate these obligations to another party and thereby defeat the legal rights of those who suffer injuries from the resulting product. The Task Force recommends, therefore, that the Commonwealth strongly consider pursuing civil enforcement action against the Skinner Tank Company as well.

The Task Force does not recommend consideration of criminal charges against STC. While the tank builder may indeed have civil liability for a discharge resulting from its failure to comply with API-650, the culpability is too attenuated to warrant prosecution. There is no question that APC accepted Tank 1338 as provided by STC and undertook certain procedures to confirm its soundness. Additionally, Ashland maintained exclusive control of the tank for almost fourteen months before the collapse. These factors, the Task Force believes, militate against prosecution.

It is important to repeat that the Task Force is not a formal prosecutive agency and that it did not engage in a rigid legal analysis of the criminal provisions which it has discussed here. The conclusions and recommendations of this report should not serve to, nor are intended to, preclude appropriate law enforcement agencies from reviewing these or additional matters if they so desire.

hoto 1 Aerial v[illegible] lapse before removal of

Photo 2 - View of tank 1367, an adjoining tank which was damaged by the collapse of tank 1338.

Photo 4 - Debris from tank 1338 after relocation to vacant property southeast of terminal.

Photo 7 - Foundation and geotextile fabric exposed after collapse.

Photo 10 - "T" weld from a conventional welded steel storage tank.

Photo 9 - Fitting for shell opening on conventional welded steel storage tank.

Photo 3 - Roof and slab of uncemented cinder block shed approximately 120' southeast of tank 1338. Cinder blocks displaced by escaping oil are in left center.

Photo 5 - 1975 photograph of Floreffe terminal showing prior tank 1338. This photo was sent by Ashland to Allegheny County Fire Marshall.

Photo 6 - Match-mark numbers on tank reconstruction project by STC at another Ashland terminal.

Photo 8 - Upper courses and roof structure of partially completed tank reconstruction project by STC at another Ashland terminal.

Photo 11 - Detail of fracture surface showing Chevron marks.

Photo 16 - Detail of fracture surface and originating flaw.
(Courtesy of Battelle Memorial Institute)

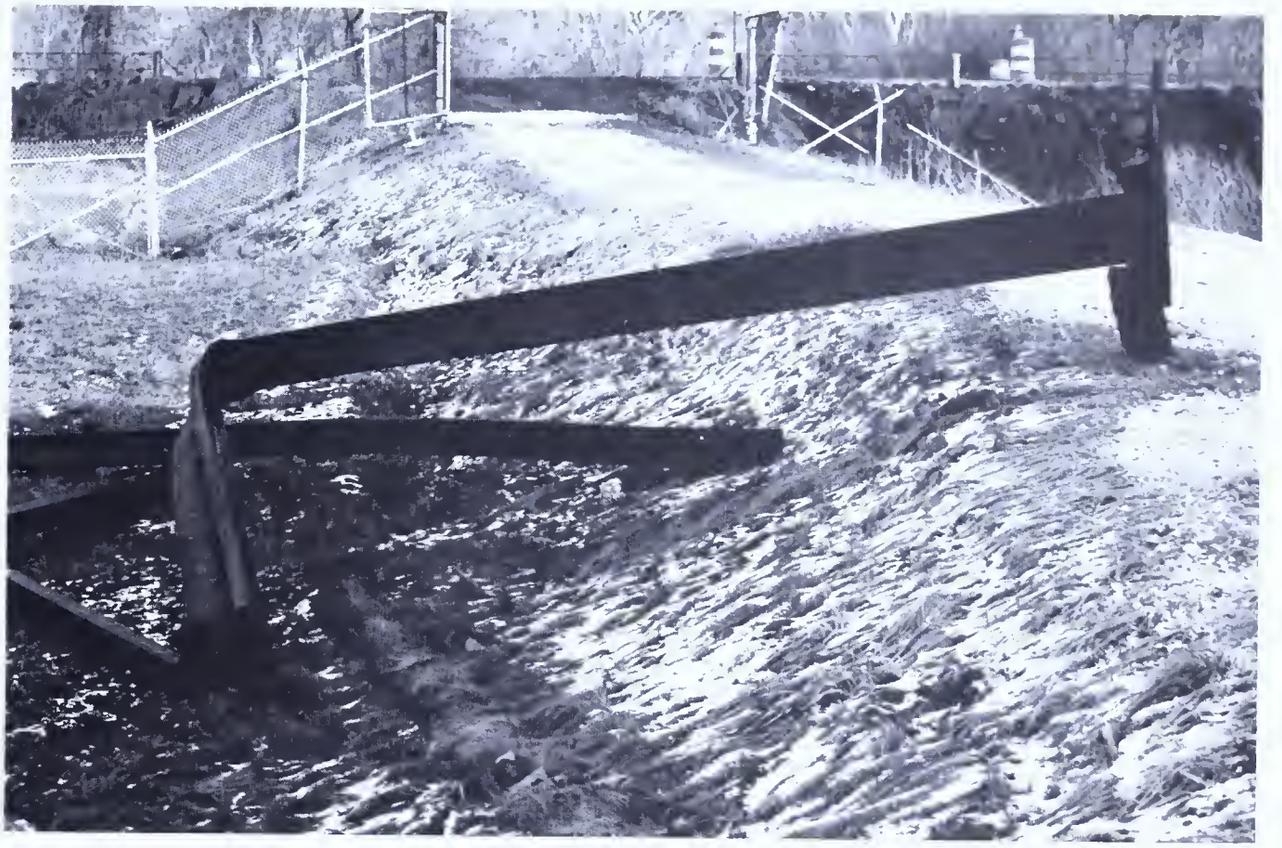


Photo 19 - Twisted and buckled roof support columns in original post-collapse locations.

Photo 12 - Fracture surface on eastern side of collapsed tank, showing curled original bottom of shell. Arrow points to originating flaw.

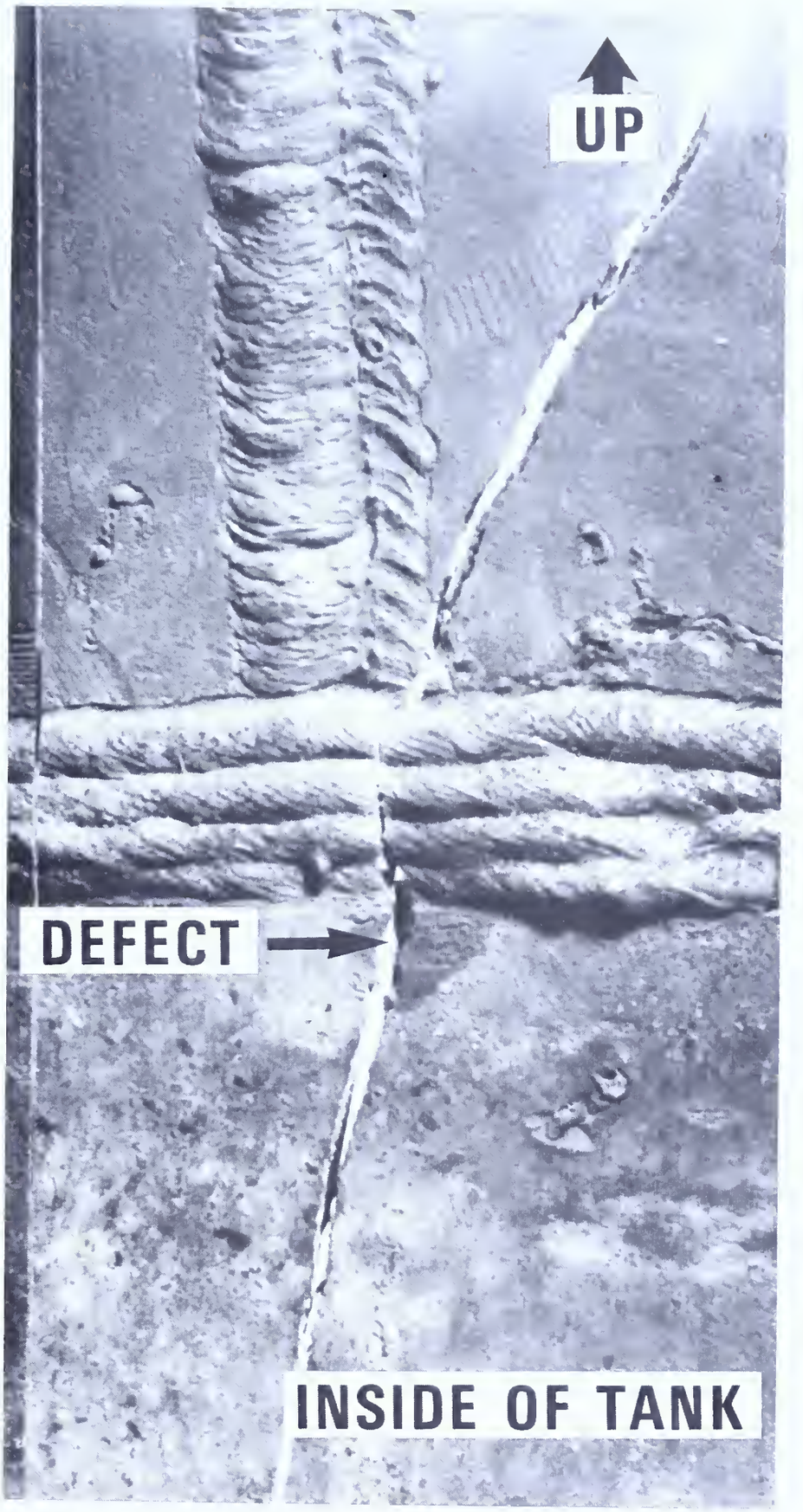


Photo 13 - Interior of tank 1338 showing "T" weld, line of fracture, and location of the initating defect. (Courtesy of National Bureau of Standards)

Photo 21 - All three roof vents collected from debris of tank 1338.

Photo 14 - Fracture surface and area of originating flaw, showing inside horizontal weld.

Photo 15 - Fracture surface showing originating flaw.

Photo 20 - Roof vent in original post-collapse location.

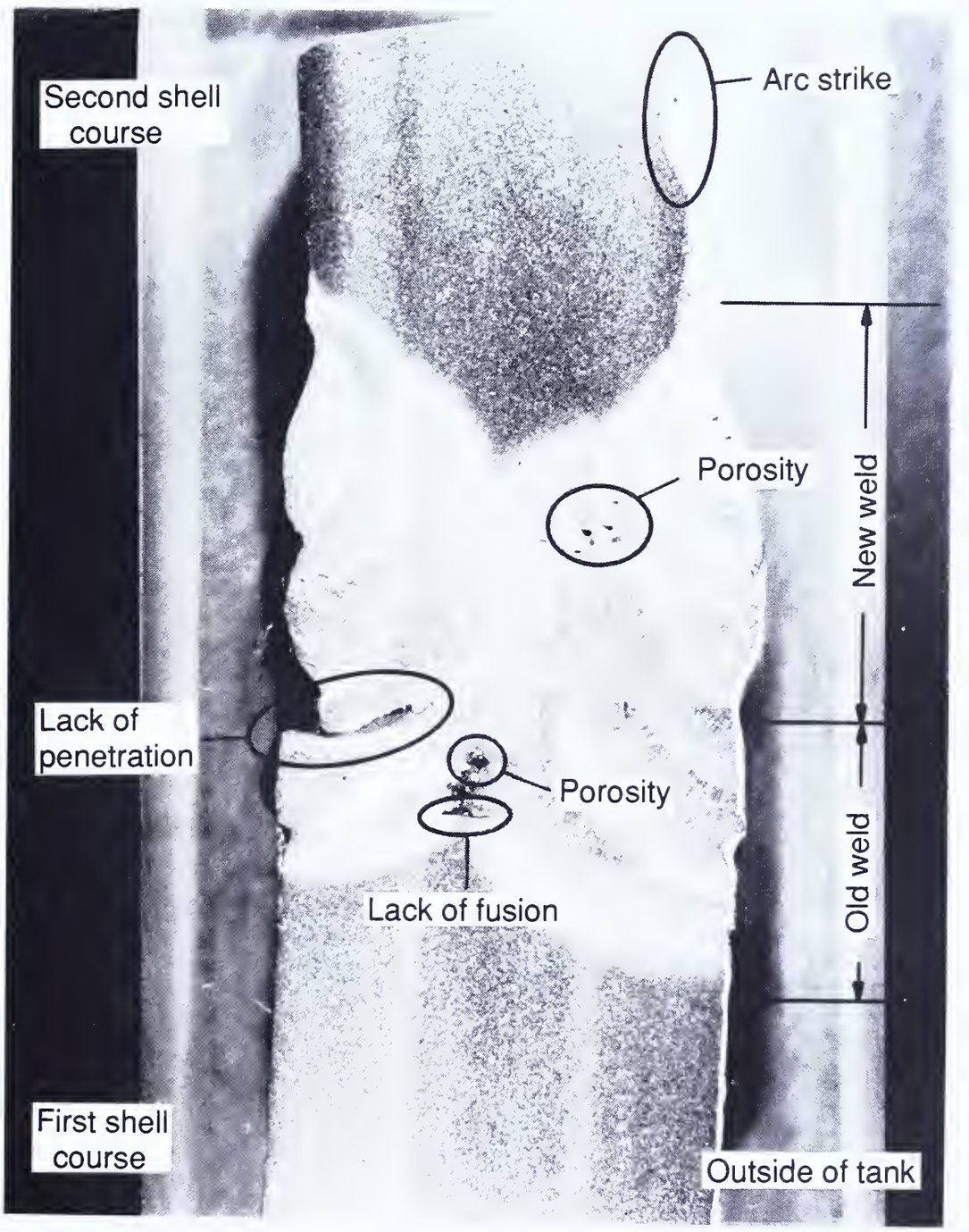


Photo 17 - Cross section of a welded joint from tank 1338 showing various defects. (Courtesy of National Bureau of Standards)

Photo 22 - Floreffe terminal with Elrama power generating station to bottom right. Arrow shows power station discharge point, utilized by oil flow to river.

Photo 18 - Tank shell after collapse.